AFFTC-TIM -03-01

A LIMITED EVALUATION OF OFF-BORESIGHT FLIGHT REFERENCE SYMBOLOGIES FOR FIXED WING AIRCRAFT HELMET-MOUNTED DISPLAYS

(Project Have SYCLOPS)

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AIR FORCE FLIGHT TEST CENTER
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14. ABSTRACT
This report presents the results of Project Have SYCLOPS, a limited evaluation of off-boresight flight reference symbologies for fixed wing helmet-mounted displays (HMDs). The overall objective was to compare three HMD flight reference displays containing own-ship status information as aids during operationally representative, off-boresight, air-to-air and air-to-ground piloting tasks. The three symbologies were the Baseline (BL), Baseline Plus (BL+) and Advanced Non-Distributed Flight Reference (ANDFR). The Air Force Research Laboratory, Human Effectiveness Directorate (AFRL/HECV) requested this testing. USAF Test Pilot School (TPS) Class 02B conducted two calibration flights and twelve VISTA flight test sorties at Edwards AFB, CA from 10 Apr 03 to 23 Apr 03, totaling 19.3 hours. Three T-38 support sorties were also flown totaling 3.5 hours. All test objectives were met.

15. SUBJECT TERMS
Helmet-Mounted Displays, HMD, Advanced Non-distributed Flight Reference, ANDFR, VISTA/F-16, Flight Symbology, Symbols, Display Systems, Air to Air Combat Simulation, Flight Tests, Simulation

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PREFACE

This technical information memorandum presents the evaluation procedures, test results, conclusions, and recommendations for ground and flight tests from the Have SYCLOPS test project. Testing was conducted by the United States Air Force Test Pilot School (USAF TPS) Have SYCLOPS Test Team at the Air Force Flight Test Center, Edwards Air Force Base, California. The USAF Test Pilot School and Air Force Research Laboratory, Human Effectiveness Directorate (AFRL/HECV) sponsored this project.

The authors thank Lieutenant Colonel James L. Wertz, the Have SYCLOPS Test Pilot School staff monitor, and Veridian Flight Research, especially Mr. Tom Landers, for their outstanding contributions to this effort.

EXECUTIVE SUMMARY

This Technical Information Memorandum (TIM) presents evaluation procedures, test results, conclusions, and recommendations for ground and flight tests of the Have SYCLOPS project. The objective was to determine if the addition of the Advanced Non-Distributed Flight Reference (ANDFR) symbology, containing own-ship status information, to a helmet-mounted display (HMD) aided in operationally representative, off-boresight, air-to-air and air-to-ground piloting tasks. The Responsible Test Organization (RTO) was the 412 TW. The test was executed by members of Class 02B of the USAF Test Pilot School, operating as the Have SYCLOPS test team.

Tests were conducted at the USAF Flight Test Center (AFFTC), Edwards AFB, California. Ground tests were executed from 9 to 14 April 2003 and flight tests occurred from 10-23 April 2003 on the Air Force's NF-16D Variable-stability In-flight Simulator Test Aircraft (VISTA). Veridian Engineering Flight Research Group and the Have SYCLOPS test team accomplished ground tests, calibration sorties, and flight tests at Edwards AFB. Two calibration flights and twelve VISTA flight test sorties, totaling 19.3 flight hours, were flown in support of this project. Ground testing and two calibration flights were accomplished prior to flight test. This project was part of the curriculum for USAF Test Pilot School. Air Force Research Laboratory, Human Effectiveness Directorate (AFRL/HECV), requested this testing.

The ground and flight tests evaluated the modifications made to a previously tested flight reference symbology set intended for use in fixed wing aircraft HMD. The HMD provided visual information to a pilot through an image projected onto the pilot's helmet visor. The projected information could be viewed regardless of the pilot's head orientation. The ANDFR symbology was designed to provide a continuous, composite, ownship state "information stamp," including airspeed, altitude, attitude, and heading regardless of pilot line-of-sight (LOS) or head movements during tactical engagements. This symbology was developed by AFRL to address and reduce clutter and occlusion problems within the head up display (HUD)/HMD and to reduce the scanning time associated with pilots visually collecting ownship status information.

This project used the HMD on VISTA to examine two different configurations of the ANDFR symbology during both ground and flight tests and compared them to the "Baseline" (BL) off-boresight HMD symbology set currently proposed for the Joint Strike Fighter (JSF). The MIL-STD-1787C HUD symbology set served as the on-boresight baseline for comparison. The BL symbology set consisted of the distributed airspeed and altitude indicators from the HUD. The second configuration was the Baseline Plus (BL+) which added the Arc Segmented Attitude Reference (ASAR) and the HUD heading tape to the BL set in the HMD. The third was the complete ANDFR symbology set as designed from the Have ATTITUDE test team's flight test recommendations in 2001.

All test objectives were met. Overall, the ANDFR symbology was found to be less beneficial to pilots than the BL and BL+ symbologies during off-boresight air-to-air and air-to-ground operationally representative tasks. The test team recommended additional development and testing of the BL and BL+ symbologies during other than day visual meteorological conditions. Suggestions for improvement and enhancement of BL and BL+ symbologies were developed and presented.

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INTRODUCTION

GENERAL

A Non-Distributed Flight Reference (NDFR) symbology set, intended for fixed-wing aircraft helmet-mounted display (HMD), was evaluated by the Have ATTITUDE test team in March and April 2001 (Reference 1). Revisions were made to this symbology based on Have ATTITUDE's recommendations. Two variations of this revised symbology were evaluated and compared to the MIL-STD-1787C HUD symbology set using the NF-16D Variable-stability In-flight Simulator Test Aircraft (VISTA). Testing was performed at the USAF Flight Test Center at Edwards AFB, California, by the Have SYCLOPS test team from the USAF Test Pilot School (USAF TPS) in March and April 2003.

USAF TPS and Air Force Research Laboratory, Human Effectiveness Directorate (AFRL/HECV) sponsored this test program as part of the TPS curriculum. All testing was supported under job order number (JON) A03HR000. Six VISTA ground simulation familiarization and test sessions were accomplished. Two VISTA calibration sorties and twelve VISTA test sorties, totaling 19.3 flight hours were flown; as well as three target sorties, totaling 3.5 hours.

This project was conducted under the authority of the Commandant, USAF TPS.

BACKGROUND

The proposed flight test evaluated the modifications made to a previously tested flight reference symbology intended for use in fixed-wing aircraft HMD. The revised symbology was designed to provide continuous own-ship status information with more precision and trend information, including: airspeed, altitude, attitude, and heading regardless of pilot line-of-sight (LOS) or head movements during tactical engagements.

Most symbology sets distributed attitude, airspeed, altitude, and heading information across the HMD field-of-view (FOV) (Reference 2). Some symbologies provided the information in close proximity to an attitude reference, but the digital information was presented on the outside of the attitude reference as in a MIL-STD-1787C HUD (Reference 3). Distributing flight information across the display FOV posed two potential usability disadvantages. First, aircraft state information distributed across the helmet FOV posed a threat to pilot usability due to the information becoming occluded by tactical symbology which also introduced significant clutter, especially when employing Fighter Data Link (FDL) symbology (Figure 1). Second, distributed information required more time for the pilot to retrieve the desired information (Reference 4). Information cannot be moved within the current/existing display FOV without creating consistency and interpretation problems. AFRL/HECV designed a symbology to address these problems, the Non-Distributed Flight Reference (NDFR).

The NDFR allowed direction and situation awareness to be maintained while the pilot was looking off-boresight during tactical maneuvering. This symbology formed a composite "information stamp".

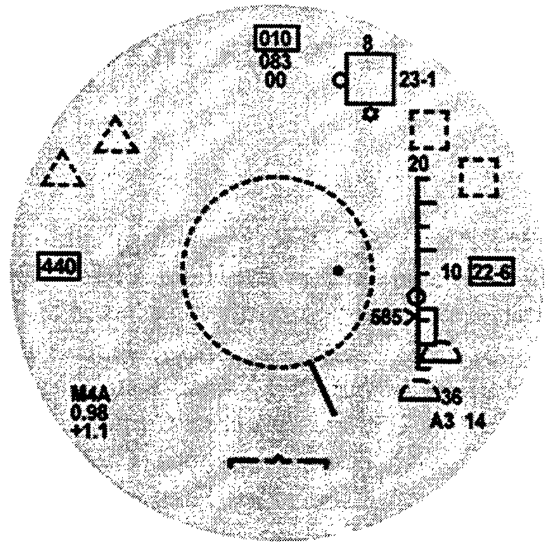


Figure 1: Distributed HMD flight reference symbology with FDL

The USAF TPS conducted testing of the original NDFR symbology during the Have ATTITUDE project. That project used the HMD on VISTA to gather data to evaluate and verify the NDFR in the flight environment and operational context. The NDFR was compared to the MIL-STD-1787C HUD symbology, which was used as a baseline, and to the Visually Coupled Acquisition Targeting System (VCATS) on the HMD. Each of the three configurations contained own-ship airspeed, heading, altitude, and attitude information. The three test symbology configurations were evaluated during ground and flight tests. Test results showed that the NDFR was better than both the HUD and VCATS symbology for recall of own-ship status, unusual attitude recognition time, and as aids during operational air-to-air (A/A) and air-to-ground (A/G) tasks. However, Have ATTITUDE made recommendations for improvement of the NDFR symbology. Revisions were made by AFRL/HECV and the new symbology was designated the Advanced NDFR (ANDFR).

This project used the HMD on VISTA to examine two different configurations of the ANDFR in the flight environment and operational context. The Baseline (BL) symbology set served as the baseline for comparison and includes the MIL-STD-1787C HUD distributed airspeed and altitude in the HMD. The Baseline Plus (BL+) configuration added the Arc Segmented Attitude Reference (ASAR) to the BL set in the HMD. The other configuration contained the complete ANDFR symbology set without any distributed own-ship status information. All three symbology sets were generated by the VISTA Simulation System (VSS) and projected onto the HMD. The on-boresight symbology set for all three configurations was the MIL-STD-1787C HUD.

The test team used a build-up approach to evaluate each configuration during this test. First, own-ship parameter recall was accomplished, followed by unusual attitude recoveries, and finally evaluation in an operational context. Pilot workload and situational awareness ratings were used to assess the symbology as an aid in the piloting tasks. Aircrew evaluated potential operational utility as well. For the purpose of comparison to the Have ATTITUDE test results, many of the test procedures and evaluation criteria were taken from the Have ATTITUDE test plan (Reference 5).

TEST ITEM DESCRIPTION

Advanced Non-Distributed Flight Reference (ANDFR) Symbology

The test item for the Have SYCLOPS test program was the ANDFR symbology set, which was to be compared to the BL and BL+. The ANDFR symbology was a modification of the original NDFR symbology and was developed by AFRL to further optimize own-ship status information, thereby enhancing the pilot's ability to quickly collect and process information from the HMD. The symbology combined digital flight information with an analog attitude reference called ASAR. The design attempted to de-clutter and localize information to afford space in the HMD FOV for targeting or other critical cueing symbology. The ANDFR was presented high in the pilot's FOV for A/G operational tasks and low in the pilot's FOV for A/A operational tasks.

The ANDFR included airspeed, altitude, flight path angle, and heading information presented digitally around a line drawing in the shape of an aircraft's wings and tail, similar in design to a HUD flight path marker (Figure 2). Airspeed (480 KIAS) was presented below this marker on the left, altitude (22600 ft) was presented on the right, flight path angle (-12 degrees) was presented in the center of the marker, and heading (090 degrees) was presented at the bottom of the symbology, below the ASAR.

This configuration was consistent with the "Basic T" primary flight reference layout, with attitude indicator in the center, airspeed on the left, altimeter on the right, and heading indicator or HSI below (Reference 6). The aircraft symbol was fixed relative to the HMD FOV and the ASAR moved around it. Attitude was interpreted by comparing the aircraft reference symbol to the attitude symbology. ANDFR used the ASAR display (Reference 7 & 8) for the attitude component of the symbol set (Figure 3).

Both the altitude and airspeed displays had rolling number displays for all digits, similar to a car odometer, providing trend information to the pilot. The airspeed was displayed in 1-knot increments, and altitude in 100 ft increments (note: illustrations and figures in this document may show different altitude increments; however, the ANDFR symbology used 100 ft increments).

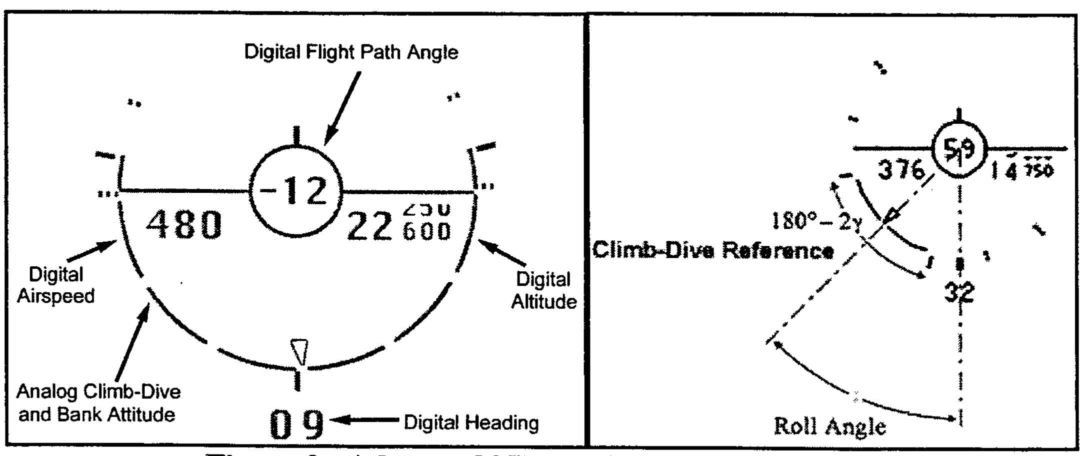


Figure 2: Advanced NDFR (ANDFR) Symbology

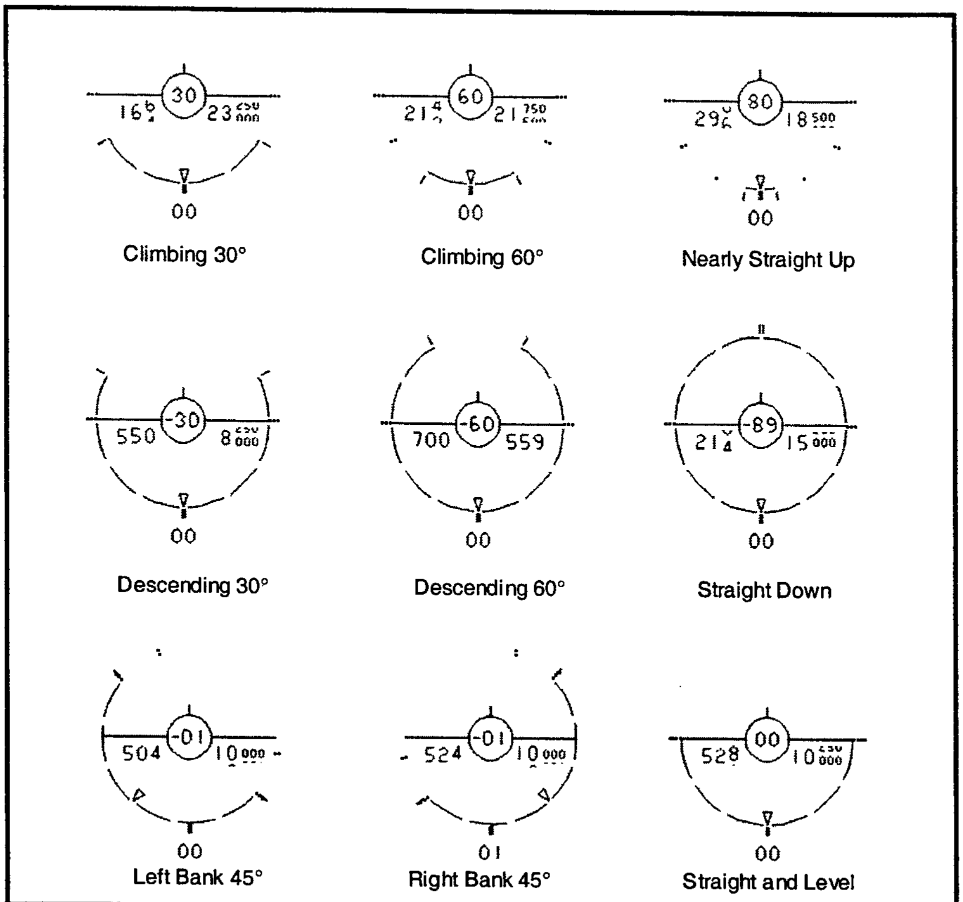


Figure 3: Advanced NDFR (ANDFR) Roll and Pitch Attitudes

The ASAR format used in the original version of the NDFR symbology was modified by the USAF as an HMD attitude reference and has flown on both the X-31 (Reference 9) and on an AV-8B (Reference 10) as part of two separate flight evaluations. Pilots reported that the symbology was easy to interpret and usable for global attitude maintenance. Further modifications, including the non-distributed digital information, were added to the ASAR during the Have ATTITUDE project.

The ANDFR provided own-ship status (aircraft state) information intended for HMD use during off-boresight viewing. The symbology was comprised of airspeed and altitude indicators in a digital odometer format (for trend), a digital heading indicator, digital climb-dive readout (precision attitude), and an ASAR. The ANDFR was designed to meet the deficiencies noted during the flight test evaluation of the NDFR conducted during the Have ATTITUDE evaluation. The flight test evaluation of the NDFR concluded that off-axis use of own-ship status symbology such as the NDFR enhances pilot performance during air-to-air (A/A) and air-to-ground (A/G) operational tasks over that of HUD use alone (Reference 11). However, it was noted that the NDFR HMD symbology lacked the ability to sufficiently convey rate-of-change information to the pilot using a pure digital readout for the airspeed and altitude indicators. It was also noted that the prototype format of the ASAR did not provide enough information to determine attitude precision concerning climb-dive or roll angles, especially near straight and level flight.

The ANDFR symbology was based on the attitude format of the final ASAR design developed by Daimler-Benz Aerospace (Reference 7 & 8). The ASAR attitude symbology conveyed climb-dive and roll using a 180° arc segment referenced against a fixed aircraft symbol. At level flight, a half circle was displayed representing a 180° attitude arc. A more complete circle was formed when diving close to 90° and almost no arc was displayed during 90° climb. Dots and gaps along the attitude arc were provided to convey ± 30° and ± 60° climb-dive, and act as a "fly to" attitude reference. Roll angles were given by the angular relationship between the fixed aircraft symbol and the center of the attitude arc rotating about the aircraft symbol (Figure 3).

In an effort to increase the precision of the attitude information conveyed, a digital flight path angle indicator was added to the center of the aircraft symbol. The remaining own-ship status information was laid out according to the "Basic T" instrument configuration with the digital odometer airspeed indicator under the left wing of the aircraft symbol, the digital odometer altitude indicator under the right wing, and a truncated (first two digits) digital heading located at the bottom of the arc underneath the ground pointer.

Baseline and Baseline Plus HMD Off-boresight Symbol Sets

The BL symbol set contained an airspeed and altitude indicator identical in format to the MIL-STD-1787C HUD symbology. The BL+ symbol set contained the same airspeed and altitude indicators found in the BL format, but added the MIL-STD-1787C HUD aircraft heading tape and the ASAR.

The three symbology sets for the test (Figure 4) were adapted for VISTA by Veridian Engineering with consultation from AFRL/HECV. The software was loaded into the VSS onboard computers, which displayed it into the HMD. The evaluation pilot was in the front seat of the VISTA with the HMD.

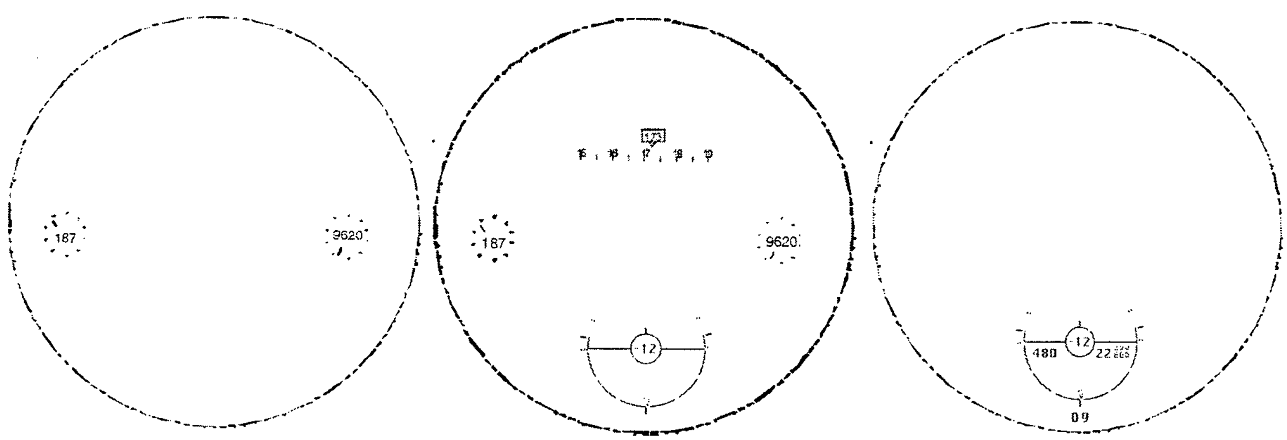


Figure 4: BL, BL+, and ANDFR HMD Symbologies

HUD Symbology

The MIL-STD-1787C HUD symbology was included to serve as an on-boresight baseline to compare the relative benefit of the HMD symbology sets. This symbology included a pitch ladder, flight path marker, and bank scale for own-ship attitude reference, airspeed and altitude indicators, and a heading tape. Both the airspeed indicator and altimeter contained a digital readout with a dial and counter pointer (Figure 5).

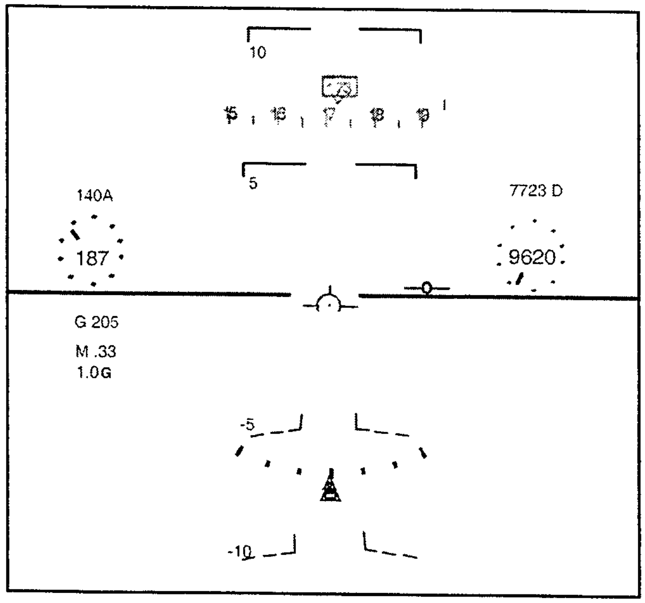


Figure 5: MIL-STD-1787C HUD

TEST OBJECTIVES

The overall test objective was to determine if the addition of the off-boresight ANDFR symbology, containing own-ship status information, to an HMD aids in operationally representative, off-boresight, air-to-air and air-to-ground piloting tasks.

Both ground and flight test were accomplished to reach this objective. The VISTA ground simulation mode was used for pilot symbology and HMD system familiarization. This ground simulation mode was also used to perform information recall ground tests, unusual attitude recoveries, A/A all aspect missile defense tests, and A/G pop attacks using the BL, BL+, and ANDFR symbologies. Flight tests were accomplished to compare the symbologies during actual unusual attitude recoveries and during A/A and A/G operationally representative tasks.

TEST AND EVALUATION

GENERAL

The overall test objective was met through the successful accomplishment of all the supporting tests. Three off-boresight helmet-mounted display (HMD) symbology sets intended for use in fixed-wing aircraft were evaluated using the NF-16D Variable-stability In-flight Simulator Test Aircraft (VISTA). Two of the symbol sets were variations of a newly modified off-boresight flight reference symbology, called the Advanced Non-Distributed Flight Reference (ANDFR). Testing was performed at the USAF Flight Test Center at Edwards AFB, California, by the Have SYCLOPS test team from the USAF Test Pilot School (USAF TPS). Ground tests were conducted from 9 to 14 April 2003 and flight tests from 10 to 23 April 2003.

Six VISTA ground simulation tests were accomplished for data collection. Two calibration and twelve VISTA flight test sorties totaling 19.3 hours were flown in support of this project. Three T-38 target sorties were required, totaling 3.5 flight hours.

The VISTA's data acquisition system (DAS) was used to record data. Testing was performed by three evaluation pilots (EPs), two evaluation flight test engineers (EFs), and one evaluation flight test navigator or weapon systems officer (EN). All evaluators provided comments and ratings. Veridian Flight Research performed specialty engineering.

Ground testing and calibration flights were accomplished prior to flight test to ensure that VISTA Simulation System (VSS) was correctly programmed and functioning properly for the ground/flight test configurations. The three off-boresight HMD symbology configurations were Baseline (BL), utilizing the MIL-STD-1787C HUD airspeed and altitude indicators; Baseline Plus (BL+), which added the Arc Segmented Attitude Reference (ASAR) analog display and MIL-STD-1787C HUD heading tape to the BL set; and the complete ANDFR.

Helmet Tracker

The helmet tracker used for determining helmet pointing angles malfunctioned during flight testing and failed to provide reliable and precise information. As a result, the designed occlusion or "blanking" of HMD symbology when looking on-boresight through the HUD did not occur during any flight test tasks. The impact was found to be minimal by the test team. Off-boresight times were consistently large enough that the few times the evaluators did look at the HUD, they remarked that the distraction was minimal. In addition, most evaluators mentioned that occlusion would probably not have occurred in any case because their head did not come all the way back to within the HUD field of view (FOV). They found themselves glancing back into the HUD while their head was still pointed about 15° to 20° off-boresight. Therefore, qualitative information from transition to and from on-boresight was considered valid. To compensate for the unreliable and imprecise helmet tracking data, evaluators estimated their percent time off-boresight, considering glances at the HUD to be "on-boresight". When necessary, these estimates were confirmed using the video tapes from the HMD and HUD displays.

INFORMATION RECALL TEST

Compare the aircrew's ability to quickly interpret the BL, BL+, and ANDFR symbologies.

Test Procedures:

This test was intended to replicate a test conducted by the Have ATTITUDE test team for the different symbology configurations (Reference 1) and was accomplished in VISTA in the ground simulation mode. Prior to data collection, the evaluators performed a series of simulated roll, loop, and barrel roll maneuvers which allowed evaluators to familiarize themselves with the symbology sets before using them for test points.

All evaluators began the ground test with the MIL-STD-1787C HUD symbology which was used as the baseline for performance comparison. Due to the previously noted problems with the helmet tracker, the virtual HUD symbology could not be properly displayed in the HMD. The visor cover was not worn (deviation from the test plan) and the evaluators used the actual HUD as the on-boresight reference. The evaluators assessed that the external visual clutter (hanger doors, etc) did not affect their performance during this task. For the HUD symbology, all evaluators began by looking straight ahead. For the BL+ and ANDFR symbologies, all evaluators accomplished the tests with their heads pointed approximately 45° off-boresight. When the evaluator called "ready," the VSS operator displayed a predetermined aircraft attitude in the HMD or HUD. The symbology was displayed for 500 milliseconds. The evaluator verbally reported heading, airspeed, altitude, bank, and flight path angle. These parameters were recorded by the VSS operator and on the VISTA data tape. Six aircraft attitudes were presented in the same sequence for each evaluator. The same procedure was repeated, with different aircraft attitudes, using the BL+ and the ANDFR symbologies.

The evaluator's verbal comments were recorded during and after each test point. The evaluator completed a questionnaire sheet immediately following the ground test session. The verbal comments and the post-test questionnaire comments were reviewed and summarized in a daily ground test report (Reference 12).

Test Results:

This task was successful in supporting the overall test objective. The evaluator responses for the five information categories: heading, airspeed, altitude, bank, and flight path angle (FPA) were scored based on Table 1. The collected data and response scores are tabulated for each evaluator in Appendix C.

Table 1: Evaluator Recall Scoring for Each Information Category

	Information Categories				
Recall Score	**Heading**	**Airspeed**	**Altitude**	**Bank**	**FPA**
Satisfactory- 2	+/- 10 deg	Correct hundreds and tens digit	Correct thousands and hundreds digit	+/- 15 deg	+/- 15 deg
Marginal- 1	+/- 30 deg	Correct hundreds digit	Correct thousands digit	+/- 30 deg	+/- 30 deg
Unsatisfactory- 0	> 30 deg	Incorrect hundreds digit	Incorrect thousands digit	> 30 deg	> 30 deg

The average pilot score for the analog information categories (bank and FPA) are shown in Figure 6. The average scores using BL+ or ANDFR for bank and FPA responses were higher than the average scores for the HUD. However, the average score for FPA using BL+ was slightly higher than that for ANDFR. Although FPA is depicted as an analog parameter, it was also available digitally in BL+ and ANDFR. The digital precision for FPA located near the center of the display could account for the higher average scores using BL+ and ANDFR. The average pilot score for digital information categories (heading, airspeed, and altitude) are shown in Figure 7. The average scores for heading, airspeed, and altitude responses were low and did not vary significantly between the three symbologies. Heading was rarely recalled correctly if noticed at all. The average scores for altitude using BL or BL+ were slightly higher than that of ANDFR, but the average score for airspeed using ANDFR was higher than that of BL or BL+. Histograms of non-pilot recall data are located in a separate data package (Reference 12). Overall, all pilots recalled analog information more precisely and more often than they did digital information.

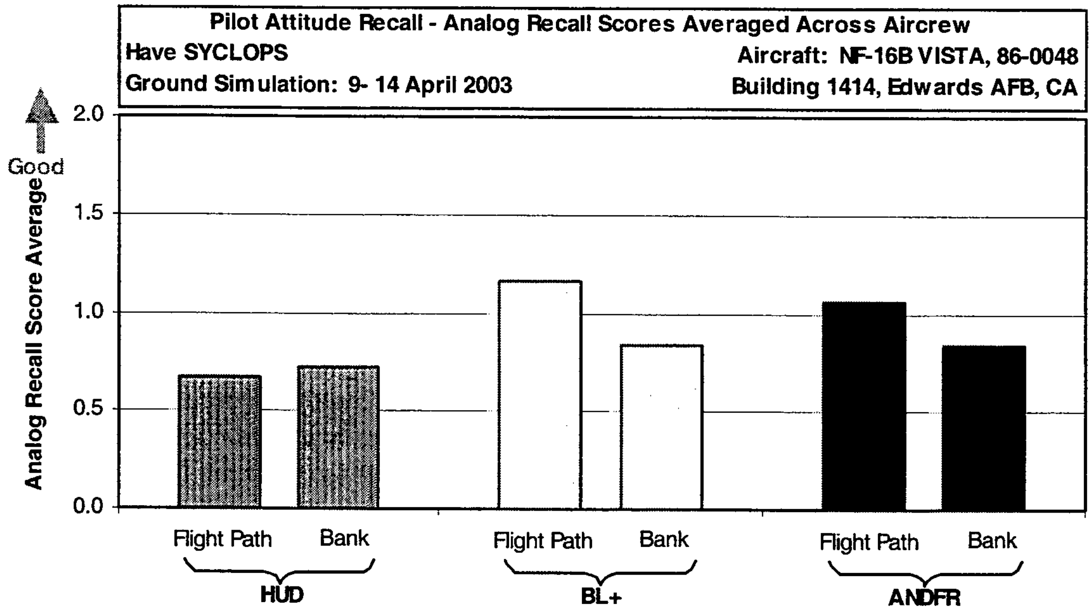


Figure 6: Analog Information Category Recall Average Scores

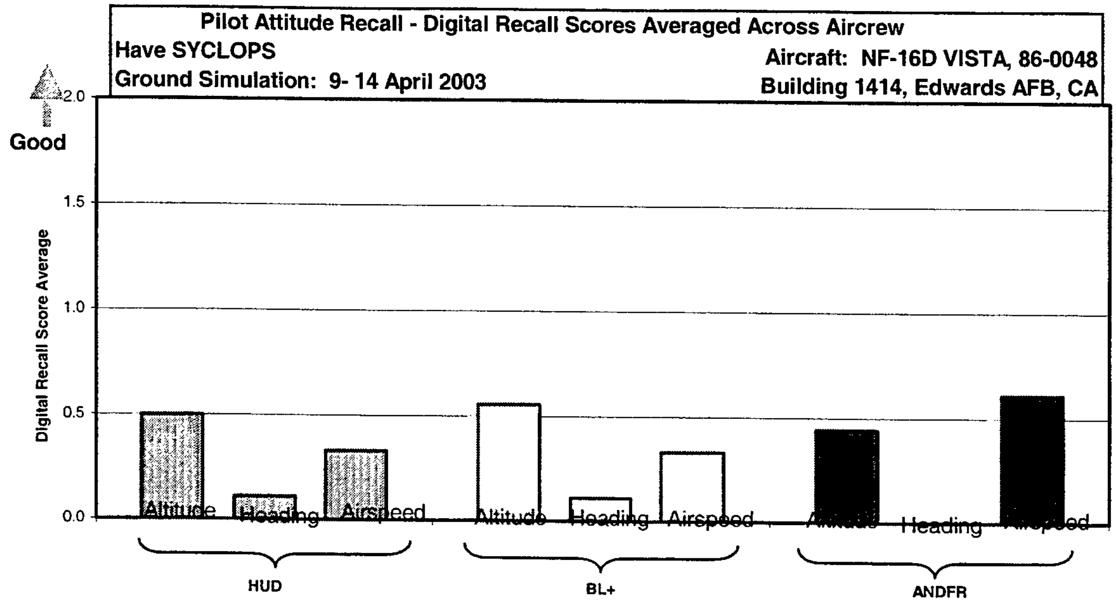


Figure 7: Digital Information Category Recall Average Scores

All possible combinations of information categories that received the highest score (2) for all categories are also shown in Appendix C. A "Mean Correct Response Frequency" (MCRF) for each symbology was computed by dividing the number of correct information category combinations by the total possible information category combinations. This parameter was developed and used by AFRL for analysis of parameter recall data collected from laboratory tests (Reference 4). The MCRF for each of the symbologies is plotted in Figure 8. When recalling static aircraft parameters, pilots were able to correctly recall precise data more often when using ANDFR than with the HUD or BL+. Likewise, pilots were able to correctly recall precise data more often using BL+ than with the HUD.

ANDFR was the preferred symbology for parameter recall. A typical pilot comment was, "ANDFR was the easiet for seeing multiple pieces of information due to their close proximity." However, pilots were still only able to focus on one to two parameters in the short amount of time. The analog pitch and bank information was easier to perceive using the Arc Segmented Attitude Reference (ASAR) without focusing specifically on those parameters. A pilot could focus on a digital parameter and sense an analog parameter with his peripheral vision. Pilots concluded that interpreting bank and pitch from the ASAR was easier when the aircraft was in a nose low attitude. However, the bank information was identified as being somewhat difficult to interpret in nose high attitudes. A better horizon reference would improve the quick recognition of bank angle at any flight path angle. **The off-boresight horizon reference should be improved (R1)[1].** Adding a horizon bar (similar to the HUD) that moves up and down and rotates relative to the digital FPA circle is one possible solution (Appendix H).

[1] Numerals preceded by an R within parentheses at the end of a sentence correspond to the recommendation numbers tabulated in the Conclusions and Recommendations section of this report.

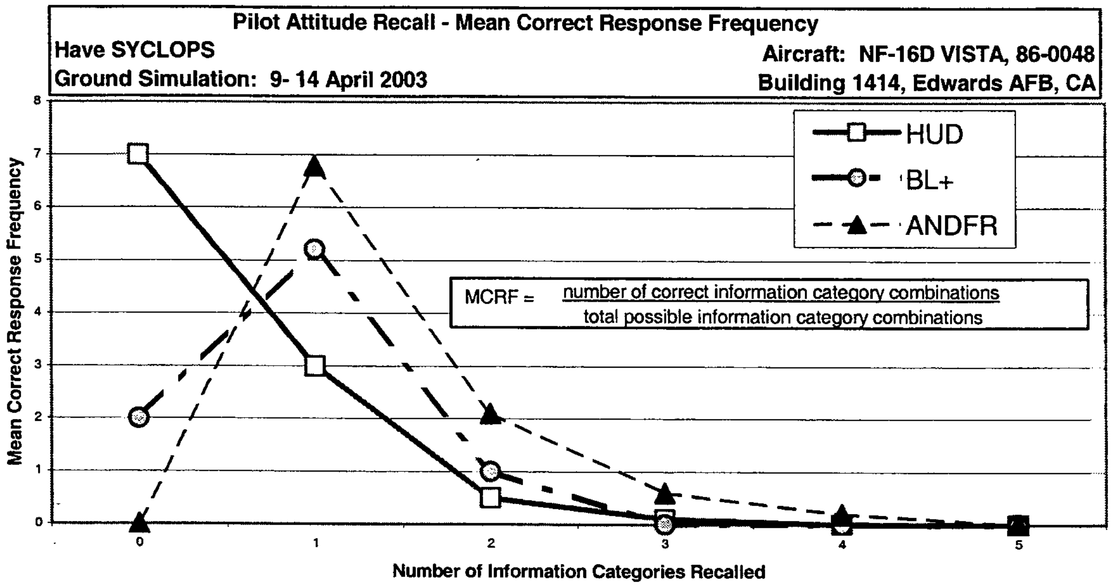


Figure 8: Parameter Recall Mean Correct Response Frequency (MCRF)

The BL+ performance was very similar to ANDFR, but the distributed nature of the altitude and airspeed information made quickly recalling multiple parameters more difficult. The existing distribution of the BL+ symbology was not objectionable, since quick parameter recognition during operational tasks usually involves recognizing parameters one at a time in a certain order of importance (i.e. bank, pitch, then altitude). Recalling more than two information categories (one precise and one approximate) with a 0.5 second flash of HUD information was extremely difficult due to the widely distributed amount of information. Using BL+ or the HUD would require more scan time to collect the same amount of information gathered using ANDFR.

UNUSUAL ATTITUDE RECOVERIES

Compare the BL, BL+, and ANDFR symbology sets as aids in recovering from unusual attitudes while initially looking off-boresight.

Test Procedures:

The test team performed unusual attitude (UA) recoveries in ground simulation and in flight using BL, BL+ and ANDFR. The visor cover was not worn (deviation from test plan) over the HMD visor. This was done so the actual HUD symbology was available during the tests for attitude information if the evaluator needed to transition to the HUD for unusual attitude recognition and/or recovery. Consequently, the outside horizon was available during flight tests as an additional aid in determining attitude information.

All evaluators began the ground and flight test points with an approximate 90° off-boresight head position. When the evaluator called "ready", the VSS operator then started the VSS masking maneuver sequence. After the masking maneuver was complete, the VSS sounded a tone, simultaneously displayed the appropriate symbology depicting the unusual attitude initial conditions, and started recording time and control inputs. At the tone, the evaluator was able to view the symbology presented and use it to recover from the displayed unusual attitude. Recovery was initiated off-boresight and completed looking on-boresight. The VSS control laws were used in VISTA for unusual attitude recovery flight tests (Appendix B).

Speed and correctness of the evaluator's first significant control inputs were recorded and compared. The evaluator's verbal comments were recorded during and after each test point. The evaluator completed a questionnaire sheet (Appendix G) for each symbology and a daily test report following the ground test session and flight test sortie. The verbal comment tapes and questionnaire comments were summarized in the daily ground/flight test reports (Reference 12).

Test Results:

The test objective was met. Quantitative ground simulation data for time to first significant input was not available due to data dropouts. However, ground simulation qualitative comments and flight test data were collected from all three EPs. Non-pilot unusual recovery data are located in Reference 12. The team tabulated the percentage of correct initial recovery inputs and the mean time to correct initial recovery inputs for both ground simulation and flight tests (Figures 9). Figure 10 displays the mean time to first significant input for incorrect inputs.

Figure 9 shows the mean times to first significant pilot input. The mean time to first correct significant input was 1.42 seconds with ANDFR, 1.44 seconds with BL+, and 1.61 seconds with BL. However, the standard deviations for each symbology varied a lot. A statistical 95% confidence level student's T-test was conducted on the times and correctness of recoveries. The test team could not conclude with 95% confidence that the mean time to first significant input using ANDFR was less than those with BL and BL+. Likewise, the test team could not conclude with 95% confidence that the correctness of the inputs using ANDFR was better than BL and BL+. See Appendix D for statistical computations. Overall, ANDFR symbology was not better than BL or BL+ with respect to mean time to first significant control input or correctness of the input.

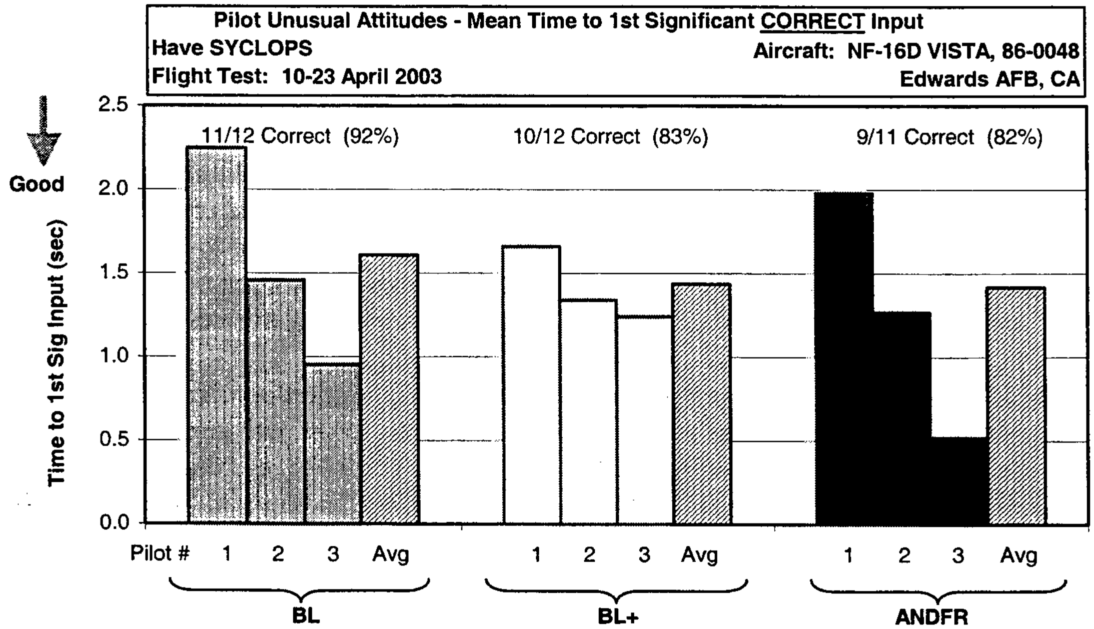


Figure 9. Mean Time to First Significant Input for Correct UAR in Flight

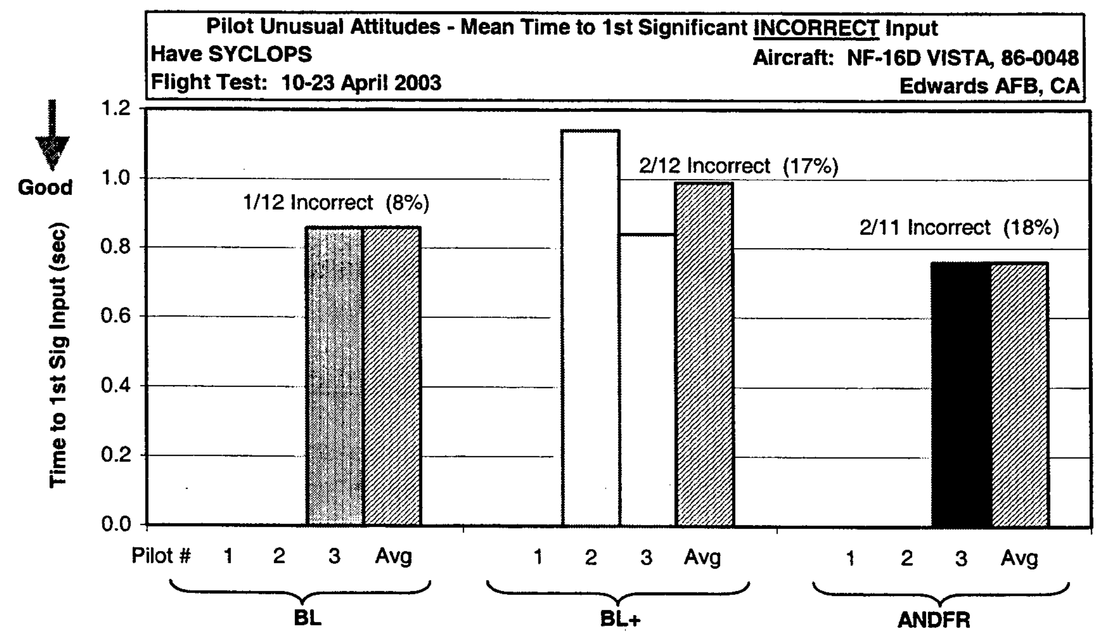


Figure 10. Mean Time to First Significant Input for Incorrect UAR in Flight

Based on pilot questionnaire results, unusual attitude parameters could be rapidly recognized using either the BL+ or ANDFR symbologies. The Arc Segmented Attitude Reference (ASAR) contained in both BL+ and ANDFR was the primary reason pilots obtained similar recognition and recovery performance with the two symbologies. Required control inputs for UA recovery were easily determined once the ASAR symbology was viewed, and confidence in spatial orientation was high before, during, and after recovery using either BL+ or ANDFR. The pilots were generally more confident of their spatial orientation throughout the entire UA recognition and recovery when the ASAR symbology was available.

The BL and BL+ digital/analog dials were intuitive and required less adjustment for all pilots due to HUD training paradigms. The heading "bar" was unanimously deemed unnecessary for a UAR. The BL/BL+ digital/analog airspeed/altitude dials provided better information to the pilots than the ANDFR digital odometer and were especially helpful in identifying extreme values and trends (rates) due to the "spinning" or movement of the dials. These spinning dials were the only way the BL symbology would cue a pilot that he was in an unusual attitude while off-boresight.

The BL required transitioning to the HUD for UA recognition/confirmation and recovery. Even though the outside horizon was available, determining aircraft flight path angle was difficult due to the disorienting masking maneuvers and lack of an off-boresight attitude reference symbology. If BL is used as the default symbology, recognition of unusual attitudes while looking off-boresight may be delayed. Addition of the ASAR format to the BL symbology set (as in BL+) would help prevent unrecognized unusual attitudes.

The BL+ was preferred by all pilots. The ASAR feedback during recovery contributed to the evaluator's quick recognition and correction of initial incorrect inputs. The ASAR was especially strong in graphically communicating the unusual attitude during nose-low conditions. The evaluator simply needed to roll and pull towards the opening of the ASAR which enabled the evaluator's ability to recover from a nose low unusual attitude completely off-boresight while maintaining situation awareness during mission tasks/target search. The only consistent deficiency of ASAR is the non-intuitive presentation of nose-high unusual attiudes. The evaluator could not simply roll and pull to the opening of the ASAR and at times would roll in the wrong direction initially.

AIR-TO-AIR TASK

Compare the BL, BL+, and ANDFR symbology sets as aids for off-boresight air-to-air operational piloting tasks.

<u>Medium Altitude All-Aspect Missile Defense Test Procedures:</u>

Pilot workload and situation awareness ratings were measured while maintaining A/C parameters within bounds during an all-aspect missile defense maneuver or "notch". The task was performed using BL, BL+, and ANDFR symbologies.

Ground and flight tests were conducted by three different EPs. Ground tests were accomplished using the VISTA VSS system to display a simulated target (target designator box 11 nm in front of VISTA) with a representative relative movement of an airborne target during the maneuver. Flight tests were conducted using a T-38 as the target aircraft. Evaluators attempted to maximize off-boresight visual search and maintenance time.

For flight testing, two predetermined waypoints, 20 nm apart, served as anchor points for the test and target aircraft. After both aircraft called "ready" the test aircraft called "turn in." The target aircraft's initial airspeed and altitude was 300 KIAS at 18000 ft MSL. The test aircraft's initial airspeed and altitude was 300 KIAS at 16000 ft MSL. At "turn in", the two aircraft turned toward each other and the test aircraft began a radar search to acquire a lock. This was seldom successful because the fire control radar in the VISTA wasn't working correctly and would shut itself down after approximately 5 minutes of use. If available, both aircraft used air-to-air TACAN for range information.

At 10 nm separation, the evaluator called "action" over the radio and began a defensive "notch" maneuver (putting the adversary aircraft at 90° off heading) based primarily on VISTA's radar range and secondarily on air-to-air TACAN. See Figure 11 for an illustration of the "notch" maneuver. If both radar range and air-to-air TACAN were not available, a 10 nm call from SPORT (AFFTC Air Traffic Control) was used to initiate the "notch." At "action," the evaluator executed an approximately 4 to 6 g, oblique turn to approximately 30° to 60° nose low, putting the target aircraft approximately 90° off heading. The test aircraft descended to the block altitude of 10000 to 14000 ft MSL and accelerated to 400 KIAS. The evaluator's goal was to descend to the simulated "floor" while achieving a simulated tactical airspeed, maintaining a 90° off-boresight angle to the target aircraft, and visually searching for the target aircraft. The simulated ground level was 10000 ft MSL and the maximum allowable airspeed was 450 KIAS due to the Viper IV helmet's ejection limit. The evaluation continued if the test aircraft descended below 10000 ft MSL, but the overall performance rating was graded as "unsatisfactory". The maneuver was terminated if the aircraft descended below 9000 ft MSL.

The safety pilot (SP) armed the VISTA's instrumentation system timing prior to the action point. VISTA recorded total off-boresight helmet time during the engagement. Timing began once the bank angle was reduced to less than 20° during the roll out from the initial "action" turn. The safety pilot called "terminate" and stopped the VISTA's instrumentation system recording 60 seconds after "action" or at intercept, whichever occurred first.

At the "action" call, the target aircraft descended to 15000 ft MSL, maintained 300 KIAS and turned 20° into the test aircraft every 10 seconds until visually acquiring the target. Once the target was in sight with the test aircraft, the target aircraft remained behind the VISTA until intercept or the "terminate" call.

After the task, the evaluator assigned a MCH rating and CLSA rating using the scales in Appendix A. The MCH rating was based on the following criteria:

Desired:	Altitude: 10000 to 11000 feet for at least 15 seconds
	Airspeed: 400 KIAS ±20 KIAS by "terminate"
Adequate:	Altitude: 10000 to 12000 feet for at least 15 seconds
	Airspeed: 400 KIAS ±40 KIAS by "terminate"
Unsatisfactory:	Failure to meet adequate criteria

Percent time off-boresight was also recorded for comparison and could be measured as desired, adequate or unsatisfactory. However, it was not used to determine the task performance rating. Off-boresight visual time:

Desired:	85% off-boresight visual time
Adequate:	65% off-boresight visual time

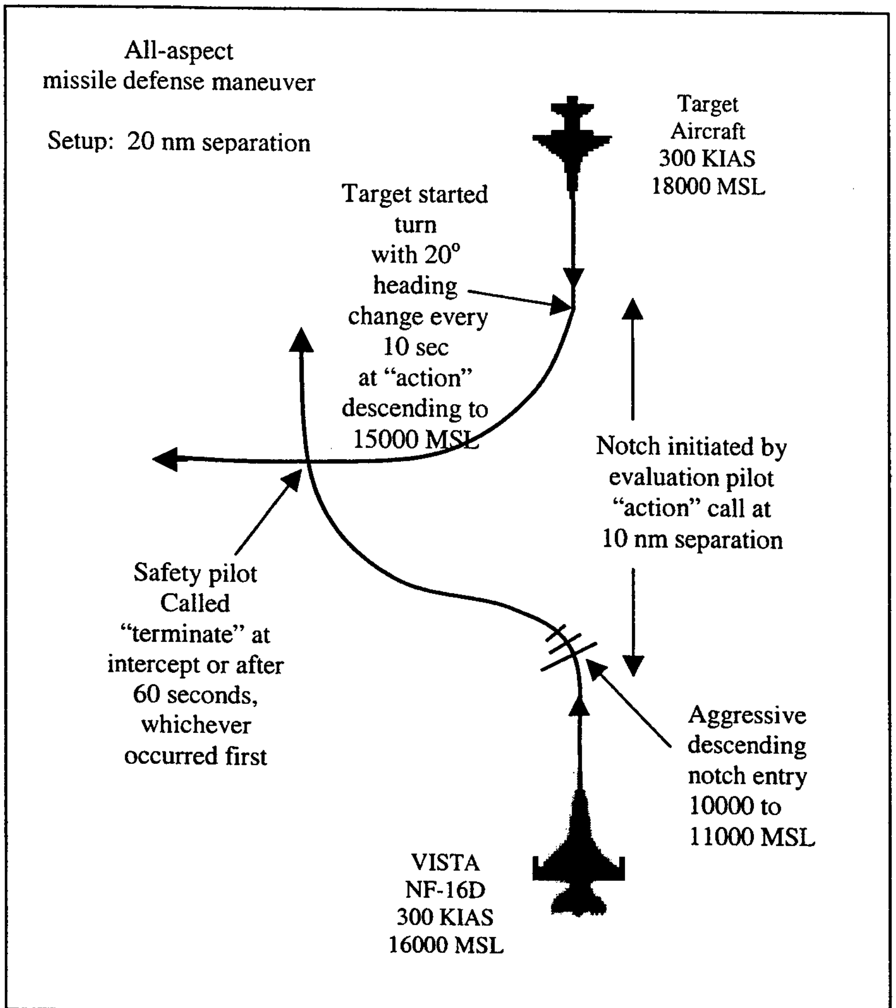


Figure 11: All-Aspect Missile Defense Maneuver

The evaluator verbal comments and ratings were recorded during and after each test point. Each evaluator completed a questionnaire sheet immediately following the tasks (ground tests) or sortie (flight tests), and completed a daily flight report following the flight test sortie. The verbal comment tapes and the post-test point questionnaire comments were included in the daily test reports.

Medium Altitude All-Aspect Missile Defense Test Results:

Each pilot completed three tasks per symbology set for a total of nine (the EF completed eight total tasks). However, due to the lack of proficiency in flying the maneuver, the evaluators felt the data from the first three tasks of each test sortie were invalid. Therefore, only data from the last six tasks (two tasks per symbology set for each evaluator) were considered valid and analyzed for results. The pilot test results are shown in Figures 12 through 15.

Figure 12 is a histogram of all MCH ratings given by the EPs after each AAMD task. The ratings are divided according to HMD symbology used, and each histogram bar represents the total number of tasks receiving that rating. MCH ratings were assigned based on the mental workload and overall performance during each task. Each AAMD task was assigned an overall performance rating of desired, adequate, or unsatisfactory, based on airspeed and altitude maintenance. Lower MCH rating numbers were better. Tasks accomplished successfully with acceptable mental workload received ratings of 1 through 3. Tasks accomplished, but only with an unacceptably high workload received ratings of 4 through 6. Ratings of 7 through 9 described a task that was not accomplished without errors and without major difficulty. A task that was impossible to accomplish reliably received a rating of 10. Figure 13 is a histogram of all CLSA ratings given by the EPs after each AAMD task. Lower CLSA ratings were better. See Appendix A and Reference 13 for more information on the MCH and CLSA scales used during testing. Percent time off-boresight was also recorded for comparison and had its own desired and adequate criteria. However, it was not used to determine the task performance rating. Figure 15 displays task performance ratings versus the tasks average percent time off-boresight for each symbology.

MCH and CLSA scales are subjective evaluations of pilot workload, task performance and situation awareness. Therefore, objective statistical analysis was not used to determine conclusions. However, subjective conclusions were drawn from the data and pilot comments.

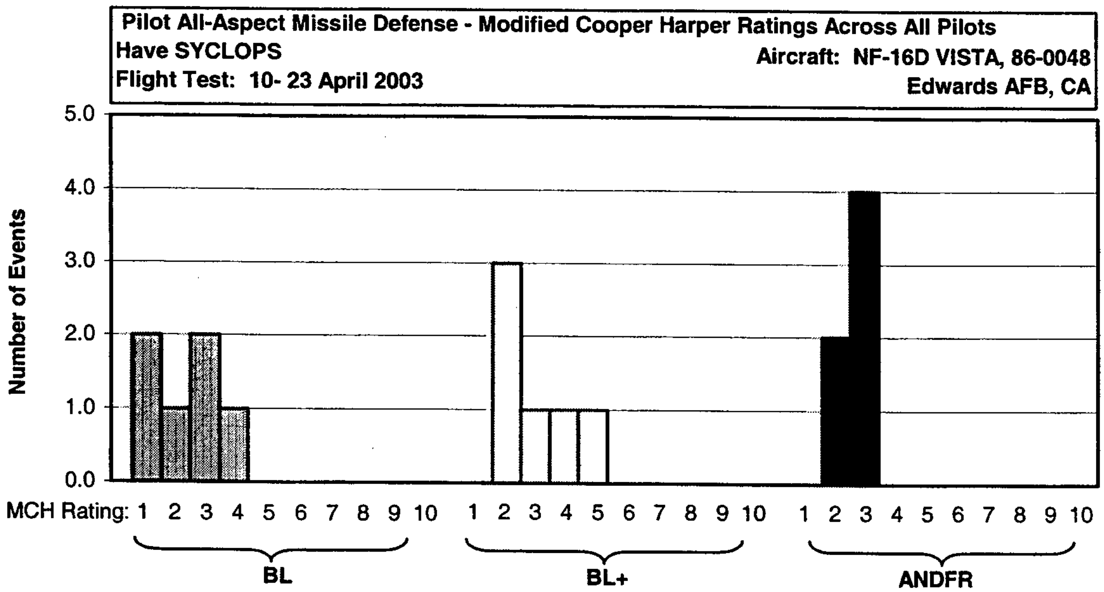


Figure 12: Modified Cooper-Harper (MCH) Ratings for AAMD Tasks

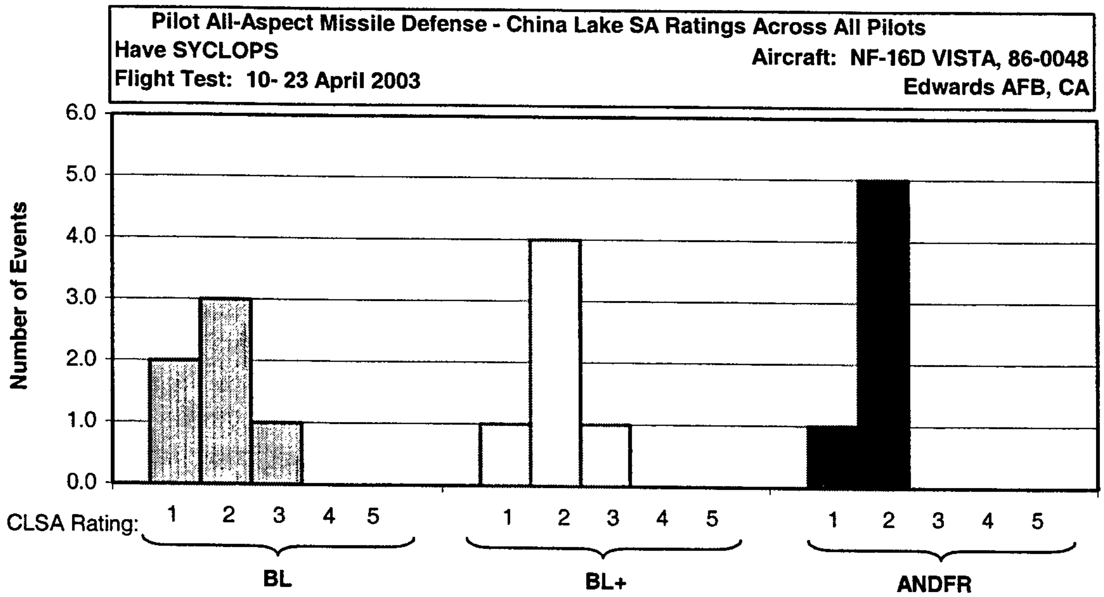


Figure 13: China Lake Situational Awareness (CLSA) Ratings for AAMD Tasks

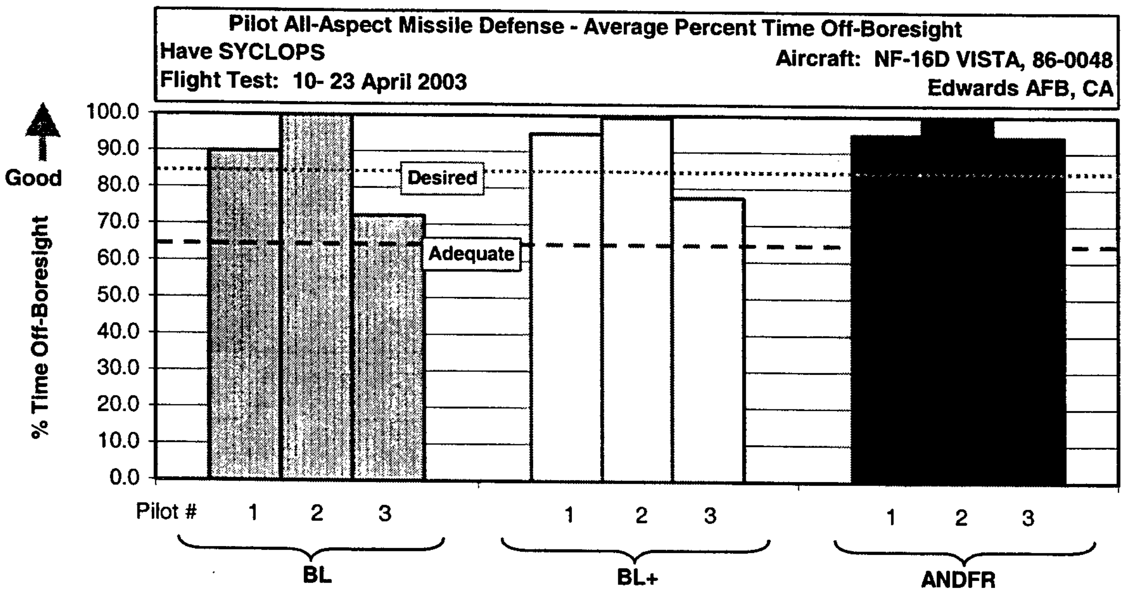


Figure 14: Percentage of Time Spent Looking Off-Boresight During AAMD Tasks

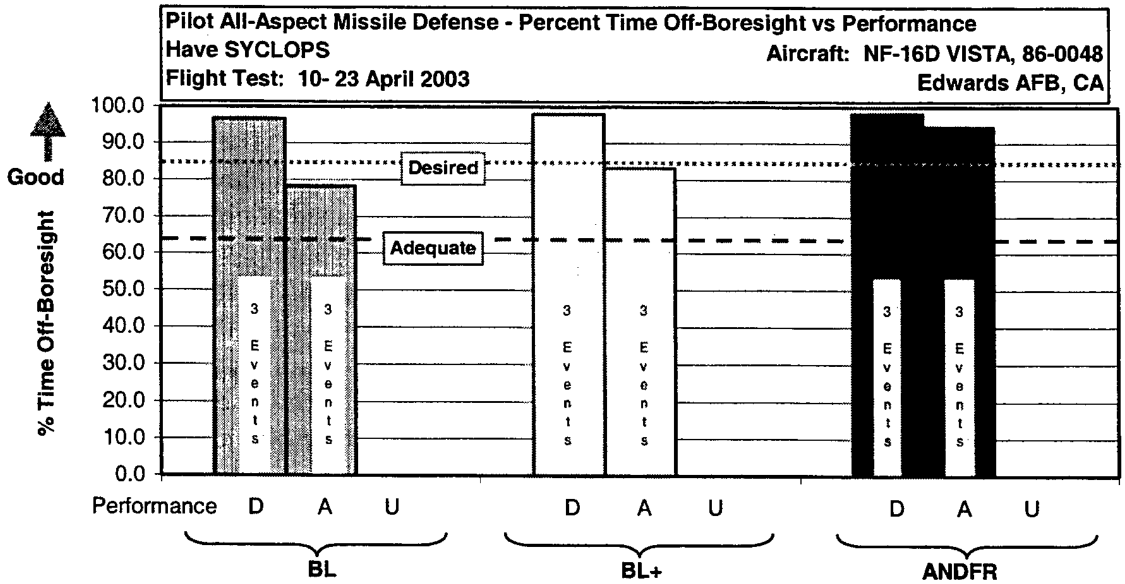


Figure 15: Overall Performance versus Percentage of Time Spent Looking Off-Boresight During AAMD Tasks

Overall, ANDFR was found to be less beneficial than BL and BL+ during AAMD tasks. AAMD tasks accomplished using the ANDFR symbology resulted in similar performance and situation awareness as those tasks accomplished with BL or BL+. However, the mental workload required to achieve the similar performance when using the ANDFR was higher. Pilots had to force themselves to use the airspeed and altitude odometers and it took more time to interpret the displayed information. The pilots spent a large amount of time off-boresight, but they spent more time focusing on the ANDFR and flying the maneuver like an instrument procedure than they did looking for the actual target. Pilots would rather spend most of the time searching for the target while being able to quickly recognize and interpret the dynamic aircraft parameter information being displayed. Although the ANDFR performed well for quickly and accurately recognizing static information (see Information Recall Test), the dynamic (trend) data displayed with the airspeed and altitude odometers required too high a mental workload and too much time for interpretation.

For a daytime scenario with a good horizon, pilots preferred the BL set for use during all-aspect missile defense maneuvers. The BL symbology was the easiest for transitioning from the HUD to off-boresight. Pilots liked the similarity between the HUD and BL airspeed and altitude displays. The off-boresight analog dials gave the pilot an exceptional sense for rate of change in altitude and airspeed. In addition to the analog trend data, the outside horizon was useful for determining relative nose low attitudes and how much to pull and smooth out the transition to level flight at the simulated ground level. Once leveled off in the desired altitude block, the analog dials provided sufficient trend data to allow pilots to spend the majority of off-boresight time looking for the target. This required minimal workload from the pilot and allowed for maximum situation awareness (SA).

Pilots concluded that the BL was satisfactory for medium altitude AAMD tasks with a good horizon. However, AAMD maneuvers in combat will most often be performed close to the actual ground. The three symbology sets evaluated did not include any radar altitude displays. The pilots still need to look out front in order to clear their flight path of any terrain or obstacles. However, the addition of an off-boresight radar altitude display would aid in determining proximity to terrain and allow the pilot to spend more time off-boresight looking for the threat which will especially aid in flight over level terrain. **A radar altitude display should be added to the off-boresight display (R2).**

The BL+ symbology was the second most preferred symbology. The similarity to the HUD in terms of the altitude and airspeed cues was preferred as with the BL set. However, the BL+ attitude display, or ASAR, may aid pilots during AAMD maneuvers performed at night or without a discernable horizon. Attempts to remain at a level altitude were difficult to perform because quickly interpreting flight path angles within approximately 20° of level flight was more difficult when looking off-boresight. The ASAR flight path angle (FPA) resolution in shallow climbs or dives was marginal which caused pilots to focus on the digital FPA indication. This required more time to read and interpret the off-boresight display and pilots found it easier to quickly glance in the HUD to check the on-boresight display of the flight path marker and horizon line. The pilots liked the off-boresight digital display of FPA for precision. However, for quick cross-checks to ensure the aircraft was not descending, pilots preferred an analog display for comparison of the flight path marker (circle with digital number inside) to the horizon line similar to the HUD. **The off-boresight analog flight path angle reference should be improved for quicker interpretation of flight path angles less than 20° (R3).** A suggested solution for improving the off-boresight horizon (discussed previously) and improving the analog FPA reference is located in Appendix H.

The BL+ off-boresight aircraft heading display was never needed and was so large that the display became cluttered and caused distraction. The pilots noted a potential benefit from having "helmet heading" available off-boresight instead of aircraft heading. A display of helmet heading is much more valuable to a pilot for use in acquiring targets visually from either communications or off-board sensor cues. Making the off-boresight heading tape shorter and changing the indication to "helmet heading" will reduce clutter and give operational pilots more important tactical information. **The BL+ off-boresight heading display should be modified to represent helmet heading and be less distracting (R4).**

AIR-TO-GROUND TASKS

Compare the BL, BL+, and ANDFR symbology sets as aids for off-boresight air-to-ground operational piloting tasks.

<u>Medium Altitude Close Air Support (CAS) Test Procedures:</u>

Pilot workload and situation awareness ratings were measured while maintaining airspeed and altitude within preset bounds during close air support (CAS) target search. The operationally representative task was accomplished in a medium altitude orbit while receiving targeting instructions or forward air control, airborne (FAC(A)). The task was performed using the BL, BL+, and ANDFR symbology sets.

The evaluators established a 2 to 6 nautical mile (nm) radius CAS orbit at 18000 ft MSL and 400 KIAS (Figure 16). The SP assisted the evaluator in maintaining desired orbit radius by verbal notification when within 1 nm of the radius limit. The evaluators called "ready" after they were established in the CAS orbit. The SP began an air strike control talk-on, started the two-minute event clock which allowed VISTA to record the evaluator's off-boresight time. The SP talked the evaluator's eyes onto the target and describing the target area details to the evaluator for two minutes. A set of randomized, standard targets, talk-on techniques, and ground references were used by the SP acting as a FAC(A). The test points were terminated after two minutes and called complete.

If the evaluator's altitude deviated by more than ±2000 ft or the CAS wheel radius limit of 2 to 6 nm was breached before the two minutes were up, the maneuver was terminated and repeated. If the evaluator successfully acquired the target before two minutes elapsed, the evaluator continued to describe target area details to maintain an operationally representative workload until the two minute limit was reached. See Figure 16 for an illustration of the CAS target search task.

The evaluator attempted to maximize off-boresight target area search time and minimize inside-the-cockpit tasks. The SP performed aircraft system crosschecks and visual clearing during the task. The VISTA recorded the amount of time that the evaluator's helmet was 30° or greater off-boresight. VISTA displayed percentage of off-boresight time, altitude maintenance, and airspeed maintenance in terms of desired, adequate or unsatisfactory performance. After the task, the evaluator assigned a MCH rating and a CLSA rating using the scales in Appendix A.

The ratings were based on the following criteria:

Desired:	Altitude maintenance: 18000 ft ±500 ft
	Airspeed maintenance: 400 KIAS ±20 KIAS
Adequate:	Altitude maintenance: 18000 ft ±800 ft
	Airspeed maintenance: 400 KIAS ±40 KIAS
Unsatisfactory:	Failure to meet adequate criteria

Percent time off-boresight was also recorded for comparison and could be measured as desired, adequate or unsatisfactory. However, this was not used to determine the task performance rating.

Off-boresight visual time

Desired:	85% off-boresight visual time into the turn
Adequate:	65% off-boresight visual time into the turn

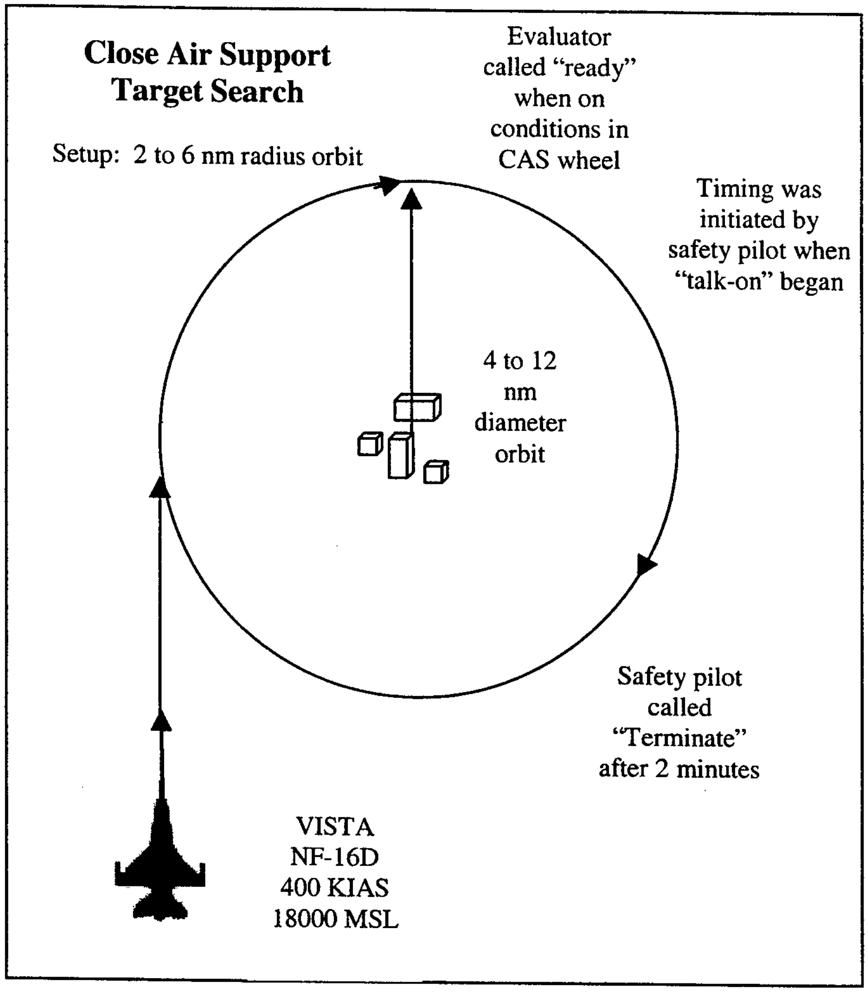


Figure 16: Close Air Support Target Search

The evaluator's comments and ratings were recorded during and after each task/test point. The comments and ratings were gathered by means of a questionnaire (Appendix G) immediately following the operational task. Voice and questionnaire comments were compiled into daily flight reports for results, conclusions, and recommendations. The cockpit voice recordings, HUD, HMD and VSS/MFD displays were also recorded and viewed post-flight to assist in writing flight reports.

Medium Altitude CAS Test Results:

Pilot workload ratings (MCH), situation awareness ratings (CLSA) and off-boresight times using the ANDFR were not all better than the BL and BL+ symbology sets. See Appendix A and Reference 13 for more information on the MCH ratings and CLSA scales used during testing. The results of the EP tests are shown in Figures 17 through 20.

Figure 17 is a histogram of all MCH ratings given by the EPs after each CAS task. The ratings were divided according to HMD symbology used, and each histogram bar height represents the total number of tasks that received that specific rating. MCH ratings were assigned based on the mental workload and overall performance during each task. Lower MCH rating numbers were better. Tasks accomplished successfully with acceptable mental workload received ratings of 1 through 3. Tasks accomplished with an unacceptably high workload received ratings of 4 through 6. Ratings of 7 through 9 described a task that was not accomplished without errors and with major difficulty. A task that was impossible to accomplish received a rating of 10.

Figure 18 is a histogram of all CLSA ratings given by the EPs after each CAS task. The ratings were divided according to HMD symbology used, and each histogram bar height represents the total number of tasks that received that specific rating. Lower CLSA ratings were better. Tasks accomplished with greater than adequate situation awareness (SA) were assigned a rating of 1 through 3. Tasks accomplished with less than adequate SA were assigned a rating of 4 or 5.

Figure 19 is a histogram of the EP's average percent time off-boresight for each symbology set. However, it was not used to determine the task performance rating. Each CAS task was assigned an overall performance rating of desired, adequate, or unsatisfactory, based on airspeed and altitude maintenance. Figure 20 is a histogram of the average percent time off-boresight for each performance level and symbology set.

MCH and CLSA scales are subjective evaluations of pilot workload, task performance and situation awareness. Therefore, objective statistical analysis was not used to determine conclusions. However, subjective conclusions were drawn from the data and pilot comments.

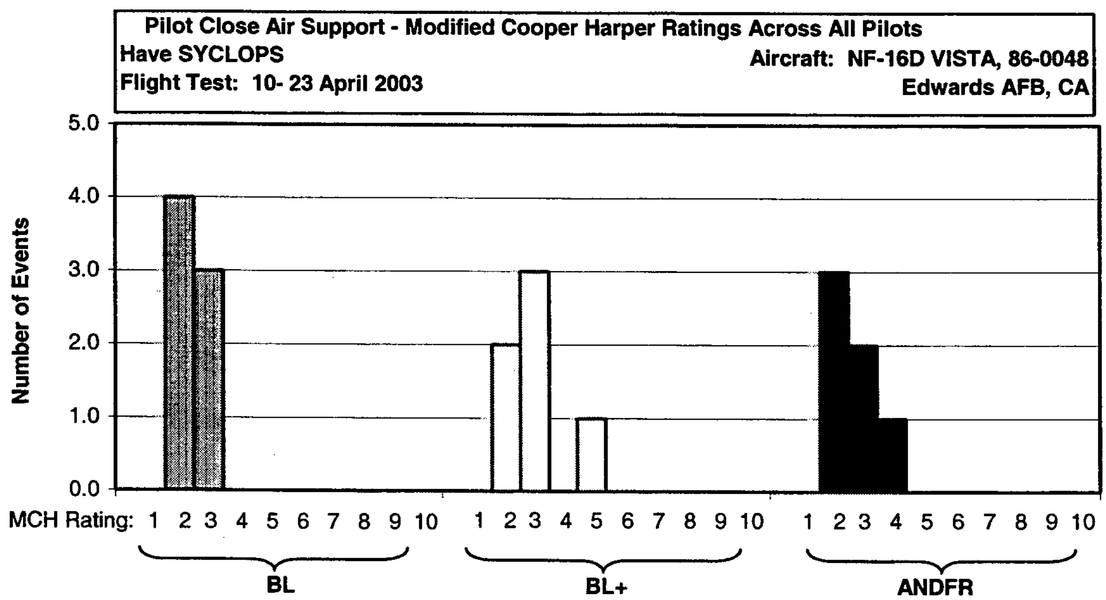


Figure 17: Modified Cooper-Harper (MCH) Ratings for CAS Tasks

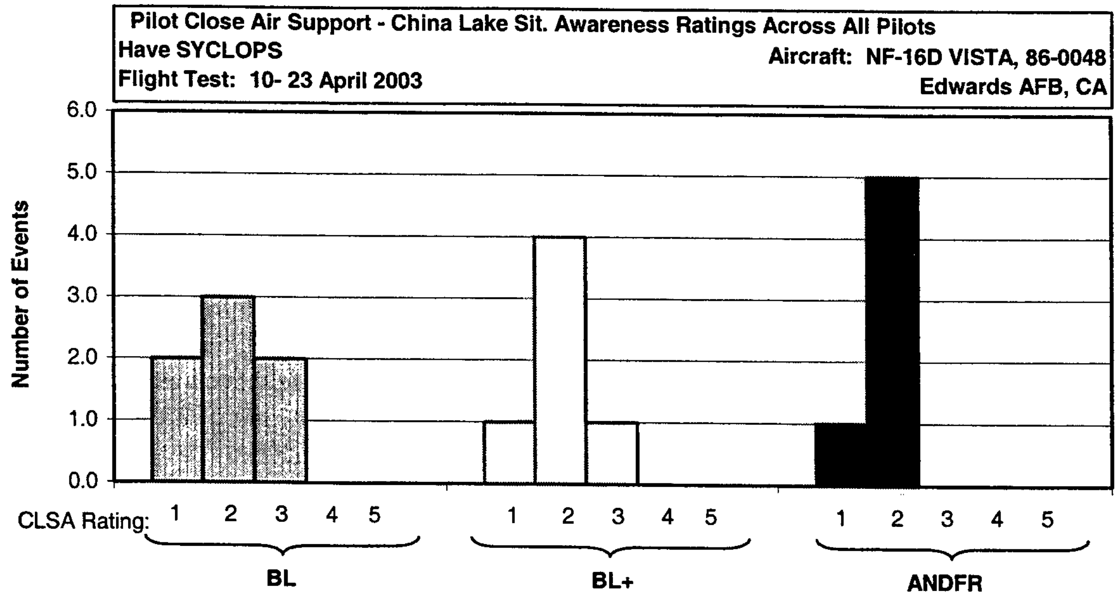


Figure 18: China Lake Situational Awareness (CLSA) Ratings for CAS Tasks

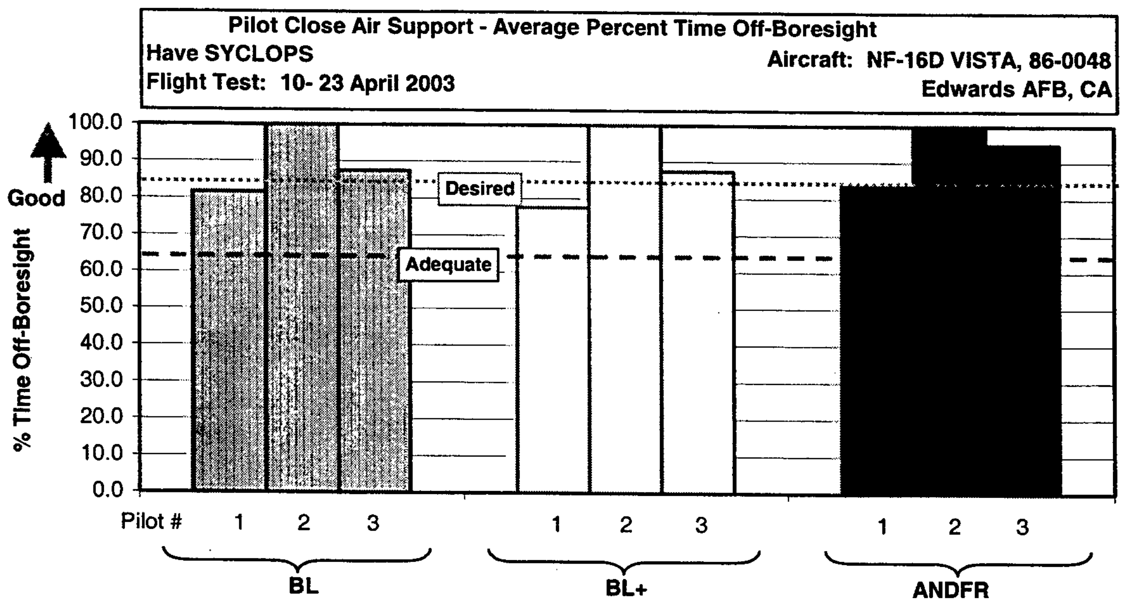


Figure 19: Percentage of Time Spent Looking Off-Boresight During CAS Tasks

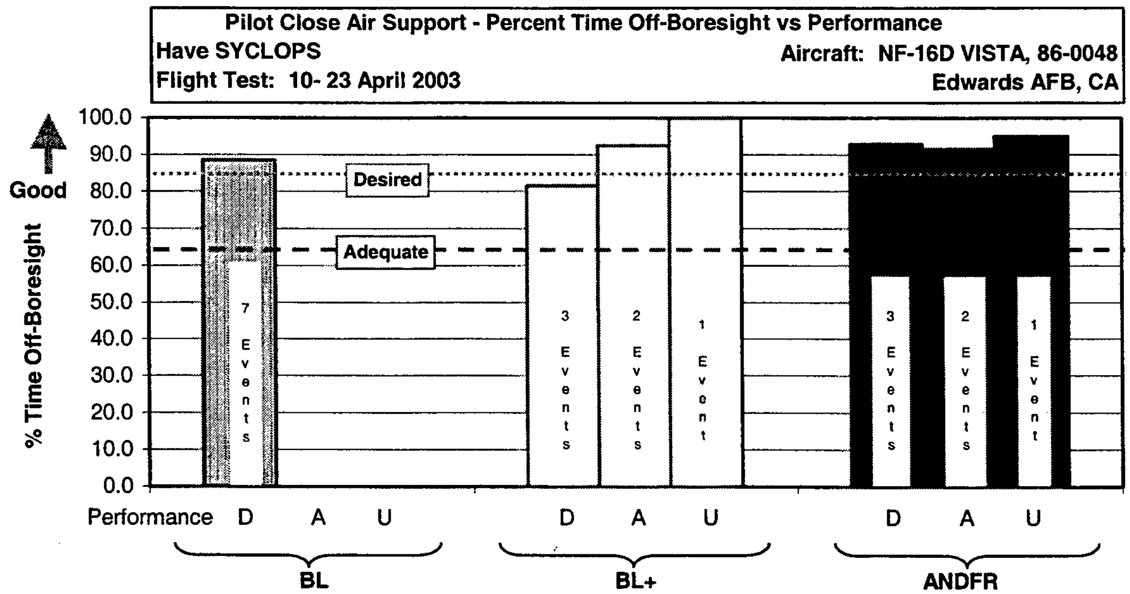


Figure 20: Overall Performance versus Percentage of Time Spent Looking Off-Boresight During CAS Tasks

The ANDFR China Lake Situation Awareness ratings (CLSA) and off-boresight times were better than those from BL and BL+. However, the BL pilot workload ratings (MCH) were much better than the other two symbology sets. The BL also provided the best performance results (see Figure 20). Using ANDFR allowed for more time off-boresight to be maintained, but with a large reduction in task performance over the BL. Therefore, the test team concluded the ANDFR was not better than the BL and BL+ during the CAS tasks.

The BL symbology was the least distracting and allowed for an easy crosscheck between altitude/airspeed and target search while operating in a day VFR environment. The similarity of the altitude and airspeed dials to the HUD display did not require a mental interpretation adjustment and allowed pilots to concentrate more on finding the target. It was also preferred due to fighter training paradigms in which the HUD and BL/BL+ airspeed/altitude cues are in the same general location and have sufficient analog trend information to accomplish mission tasks. The EP workload was lower with the BL symbology set and SA during task execution was rated very good.

The shortfalls of the ASAR were the fact that the attitude reference was not precise enough to fly the aircraft with the precision required for the task and its location was too high in the pilot's field of view for this medium altitude air-to-ground task. Interpreting the ANDFR digital odometer-style indicators for trend information caused an increase in workload.

Low Altitude Pop Attack Test Procedures:

Ground and flight tests were conducted by three different EPs using the same attack procedure. Ground tests were accomplished using the VISTA VSS system to display a simulated target with a representative relative movement of a ground target during the attack. Flight tests were conducted using unfamiliar targets and ground references so EPs were required to perform more target area search during the climb. The EPs attempted to maximize off-boresight visual search and maintenance time.

The EPs ingressed direct to the target at 500 feet AGL and 420 KIAS. The SP armed the VISTA's instrumentation system timing prior to the action point. At 4.5 nm from the target, the evaluation pilot turned 30° away from the attack heading using a 4 g level turn and then rolled wings level (a "check"-turn). The pilot then initiated a 30° climb using 4 g in 2 seconds. The climb continued until roll-in was initiated at 3200 ft above the target elevation ("pull down" altitude). The VISTA recorded the amount of time that the pilot's helmet was 20° or greater off-boresight towards the target. Off-boresight timing started after the check turn rollout (<19° bank) and continued until the roll-in after the climb (>21° bank). Average climb angle was computed from 4 seconds after the check turn rollout (<19° bank) to the roll-in after the climb (>21° bank). The VISTA instrumentation system monitored and displayed the percentage of off-boresight time and average climb angle maintenance in terms of desired or adequate performance. Roll-in altitude (altitude when bank >21°) was also displayed by VISTA. After pull down, the EP continued the attack with a simulated 20° dive bomb delivery and subsequent climbing safe escape maneuver. The safe escape maneuver was flown using 5 g in 2 seconds until 30° nose high. The pilot performed a 2 to 4 g slicing turn back to low altitude while changing heading by at least 90°. See Figure 21 for an illustration of the pop attack. The minimum airspeed allowable during the maneuver was 300 KIAS. The maximum allowable airspeed was 450 KIAS due to the Viper IV helmet's ejection limit. The safety pilot performed aircraft system crosscheck, visual clearing, and monitored ground clearance altitudes and dive angles. After the task, the EP assigned a MCH rating and CLSA rating using the scales in Appendix A. The MCH ratings were based on the following criteria:

Desired:	Climb angle maintenance: Average 30° ± 2°
	Pull-down altitude tolerance: Planned ± 200 feet
Adequate:	Climb angle maintenance: Average 30° ± 3°
	Pull-down altitude tolerance: Planned ± 400 feet
Unsatisfactory:	Failure to meet adequate criteria

Percent time off-boresight was also recorded for comparison and could be measured as desired, adequate or unsatisfactory. However, it was not used to determine the task performance rating.

Off-boresight visual time:

Desired:	70% off-boresight visual time
Adequate:	50% off-boresight visual time

The EP's verbal comments and ratings were recorded during and after each test point. Each EP completed a questionnaire sheet immediately following the tasks (ground tests) or sortie (flight tests), and completed a daily flight report following the flight test sortie. The verbal comment tapes and the questionnaire comments were included in the daily reports (Reference 12).

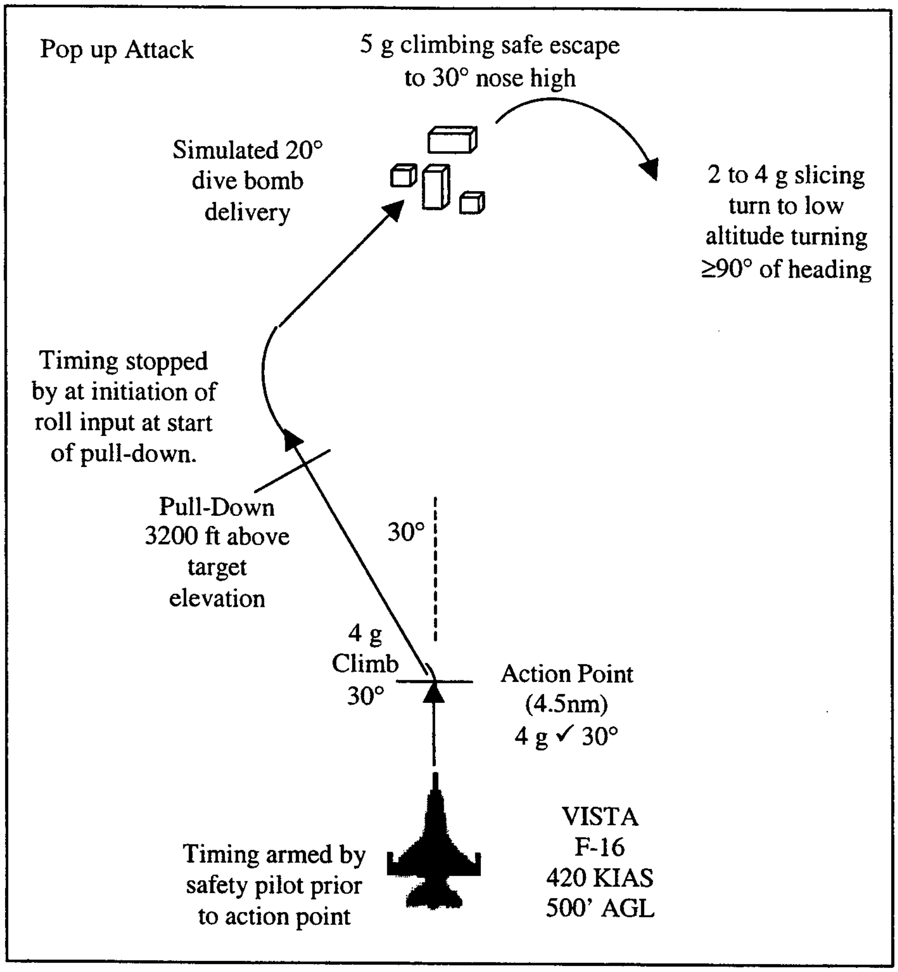


Figure 21: Pop Attack

Low Altitude Pop Attack Test Results:

The results of the tests are shown in Figures 22 through 25. Figure 22 is a histogram of all MCH ratings given by the EPs after each Pop Attack task. The ratings are divided according to HMD symbology used, and each histogram bar represents the total number of tasks receiving that rating. MCHRs were assigned based on the mental workload and overall performance during each task. Each Pop Attack task was assigned an overall performance rating of desired, adequate, or unsatisfactory, based on airspeed and altitude maintenance. Lower MCH numbers were better. Tasks accomplished successfully with acceptable mental workload received ratings of 1 through 3. Tasks accomplished, but only with an unacceptably high workload received ratings of 4 through 6. Ratings of 7 through 9 described a task that was accomplished with errors and major difficulty. A task that was impossible to accomplish reliably received a rating of 10.

Figure 23 is a histogram of all CLSA ratings given by the EPs after each Pop Attack task. Lower CLSA ratings were better. See Appendix A and Reference 13 for more information on the MCH and CLSA scales used during testing. Percent time off-boresight was also recorded for comparison and could be measured as desired, adequate or unsatisfactory. However, it was not used to determine the task performance rating (Figure 24). Figure 25 displays task performance ratings versus the tasks average percent time off-boresight for each symbology.

MCH and CLSA scales are subjective evaluations of pilot workload, task performance and situation awareness. Therefore, objective statistical analysis was not used to determine conclusions. However, subjective conclusions were drawn from the data and pilot comments.

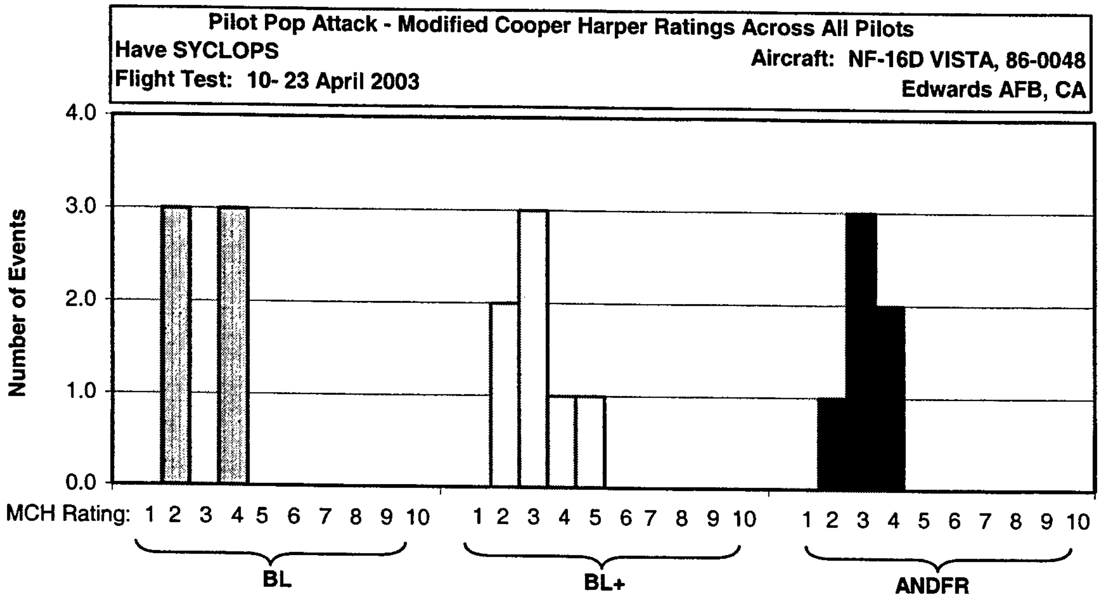


Figure 22: Modified Cooper-Harper (MCH) Ratings for Pop Attack Tasks

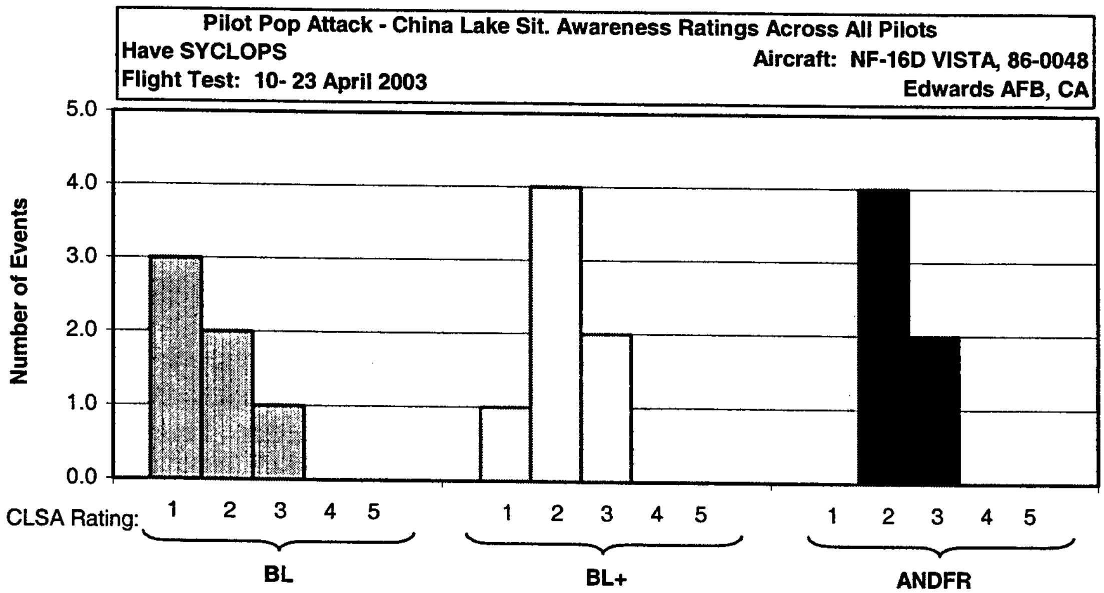


Figure 23: China Lake Situation Awareness (CLSA) Ratings for Pop Attack Tasks

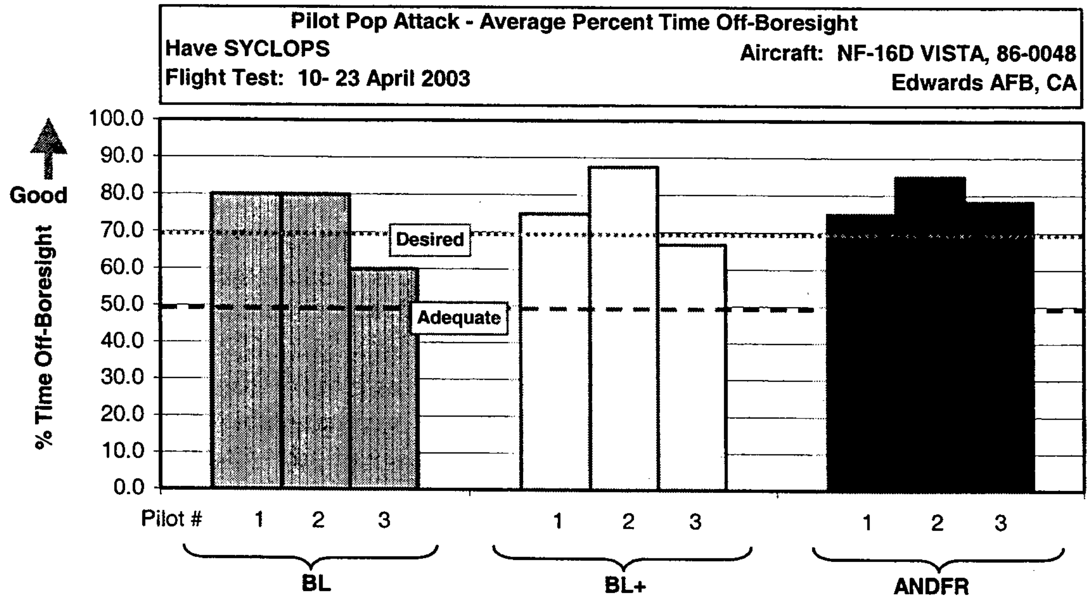


Figure 24: Percentage of Time Spent Looking Off-Boresight During Pop Attack Tasks

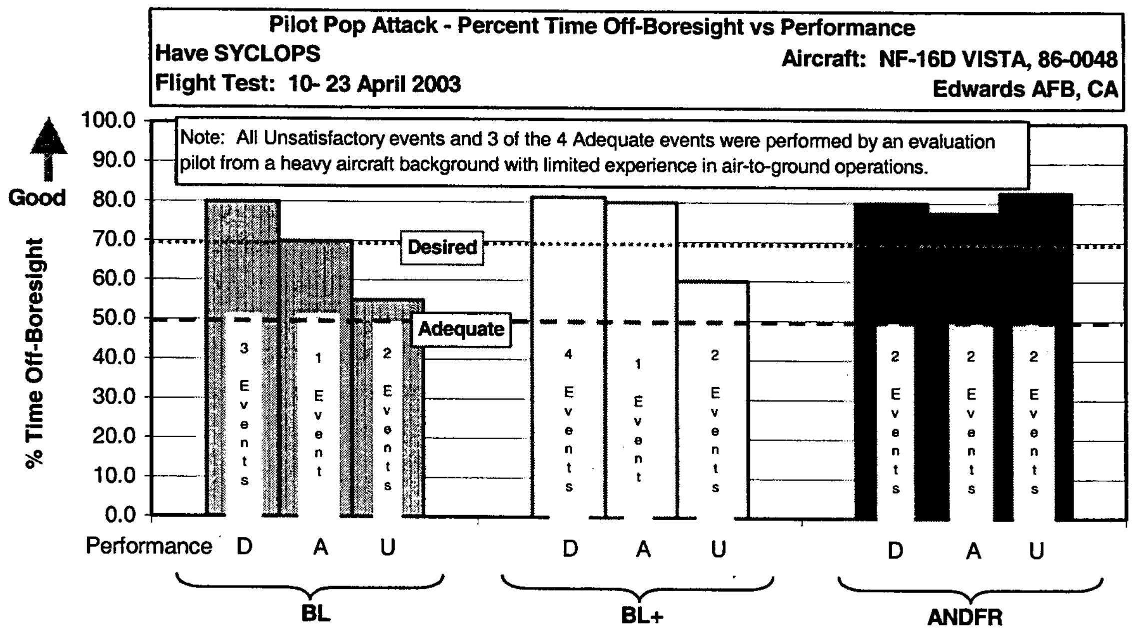
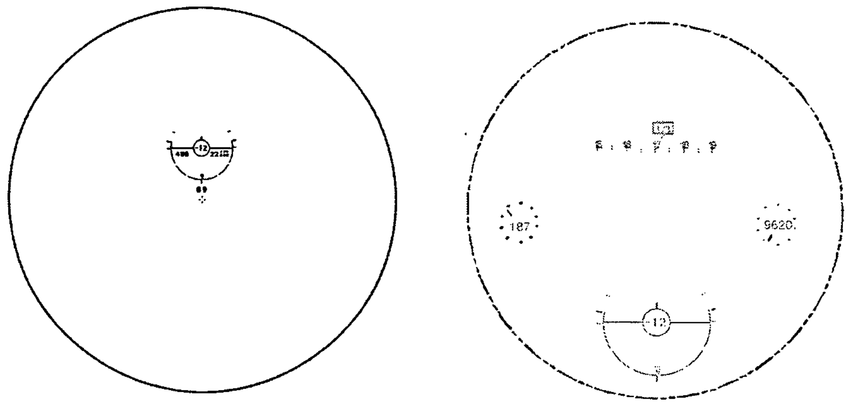


Figure 25: Overall Performance versus Percentage of Time Spent Looking Off-Boresight During Pop Attack Tasks

Pilots had better SA during the task with BL than they did with ANDFR. In addition, task performance was better using the BL+ symbology than with the ANDFR. Pilots liked the consolidated display of the ANDFR, but the altitude and airspeed odometers were difficult to read under dynamic conditions. This made it difficult to quickly interpret the altitude and degraded the pilot's ability to anticipate when to role in to the target. The need for quick interpretation of altitude and climb angle was the driving factor in the task. The pilot should be able to use most all off-boresight time searching for the target and threats. Transitioning from using the HUD's analog dials to the ANDFR odometers required greater mental processing and significantly more time staring at the display in order to correctly interpret the information and how fast it was changing. This resulted in an objectionably small amount of time available to find the target. It would be easier to glance in the HUD for the altitude and airspeed information than to focus on the odometers. In addition, the placement of the ANDFR for air-to-ground tasks was too high. During off-boresight target search, pilot's eyes scanned low in the HMD field of view (FOV) without moving their heads much in elevation. As a result, the crosscheck of the HMD displayed symbology required the pilot to scan higher in the HMD FOV for the information. The ANDFR was placed so high that the pilot's eyes had to scan up an excessive distance and led to mental strain, increased time to gather the desired information, and distraction from the target. The transition and interpretation difficulties associated with the ANDFR would inevitably cause pilots to become annoyed with the symbology and ignore it completely. In this case, the ANDFR may not be used when it was needed for unusual attitude recognition.

During a daytime low altitude pop attack, pilots preferred using the BL symbology. The transition to off-boresight was easy and the cross-check scan pattern did not change when retrieving altitude and airspeed information. A typical pilot comment was "The cross-check and interpretation of the symbology was so intuitive that I could focus all my mental effort on trying to find the target." (Reference 12). Requiring a pilot to change his mental habit patterns when transitioning from on to off-boresight should be minimized if possible. Pilots did need to look inside one or two times for flight path angle information. However, pilots naturally retrieved this information very quickly by moving their heads a small amount while shifting their eyes across the majority of the angular distance into the HUD. **The Baseline symbology should be used as the default off-boresight symbology set (R5).**

Pilots liked using the BL+ symbology second best. The similarity of the altitude and airspeed dials made transition to off-boresight and symbology interpretation easy. Although pilots did not need an attitude reference during a day pop attack, they did like having the attitude reference available for use in determining flight path angle in the climb. In addition, the ASAR was useful when maneuvering back to low altitude after the attack and looking back at the target area for threats. The ASAR could potentially aid in low altitude attacks at night and potentially prevent unusual attitudes or spatial disorientation when off target. However, the position of the ASAR in the BL+ symbology was not correctly programmed (too low in the FOV at 98 mils below HMD center) for the low altitude pop attack (i.e. not IAW the test plan at 65 mils above HMD center). The ANDFR location, high in the FOV, was programmed correctly for the low altitude pop attack task (Figure 26).



ANDFR **BL+**

Figure 26: Actual Pop Attack Symbologies Programmed

Although the ANDFR was programmed and displayed correctly, the BL+ attitude reference was incorrectly displayed low in the HMD FOV as for the air-to-air task (Figure 26). The impact of this programming error was actually beneficial. The high positioning of the ANDFR was objectionable as previously noted. However, the low positioning of the ASAR in the BL+ symbology was much better. The lower position of the ASAR allowed for a quicker cross check of flight path angle, reduced the mental strain on the pilot, and allowed for more time to be spent looking for the target than scanning up to see and interpret the symbology. One pilot noted that it was slightly too low because it covered up the top portion of the target area. **The off-boresight attitude reference display should be positioned low in the HMD field of view for easy parameter cross check during air-to-ground tasks (R6).**

The off-boresight display of aircraft heading was not used or needed during the task, but the positioning was so high above where the pilots eyes were looking (low in the HMD FOV) that the symbology was not distracting.

MILITARY UTILITY

Helmet Fitting and Stabilization:

Correct vertical placement of the HMD display along the pilot's Frankfort plane or natural eye line of sight was very difficult with the test helmet. Correct helmet fitting was critical and had to be adjusted for each aircrew member prior to flight. Many times the center of the HMD display would be positioned just above the HUD symbology when looking on-boresight. Prior to tasks, aircrew would tilt the helmet forward on their head in order to correctly align the HMD display with the HUD. The vertical and lateral freeplay in the helmet occasionally caused the symbology to move with the helmet's movement. For accurate and precise off-boresight weapons cueing tasks, the helmet fitting would need to be comfortable and ensure alignment with the pilot's natural sitting eye line of sight. In addition, the HMD symbology should be stabilized relative to the aircraft body axis. The alignment and stabilization of the HMD symbology will be crucial to effective implementation of the virtual HUD concept in any fighter type aircraft intending to use the HMD symbology for accurate and precise weapons employment.

Unusual Attitude Recoveries:

The ASAR included in the BL+ and ANDFR was useful in determining roll direction and relative pitch attitudes during unusual attitude recoveries. Even though the BL symbology did not greatly enhance the pilot's ability to recognize unusual attitudes while looking off-boresight, pilots still preferred to fly with BL for operational tasks during the day. Assuming that pilots would normally fly around with the BL set, an automatic addition of the ASAR display when the ground collision warning system activates or when the aircraft descends below the programmed radar altitude warning height could provide pilots with important time-critical information to ensure recovery.

The addition of the ASAR could be beneficial at night, in IMC, or when a discernable horizon does not exist. While operating with NVG's often provides a better horizon at night, certain conditions (i.e. low moon illumination) could degrade the available horizon. Having the ASAR displayed under these conditions could aid aircrew from becoming disoriented while looking off-boresight. Having the ASAR displayed during IMC formation could assist wingmen from becoming spatially disoriented while flying on the flight lead's wing. Allowing pilots to select which symbology they want to use (BL, BL w/ASAR, BL w/ASAR and helmet heading, etc.) would enable pilots to determine which combination is needed or desired. For example, pilots could fly with BL during day VFR conditions and switch to BL w/ASAR when the weather deteriorated. **System integration of off-boresight HMD symbology should incorporate a pilot programmable declutter option (R7).**

Air-to-Air:

When considering the addition of weapon/sensor cues in the HMD, the BL symbology would be the most useful and least distracting off-boresight symbology. Additionally, the BL symbology will allow pilots to quickly determine their "energy" (altitude and airspeed) and could be beneficial during defensive fighter maneuvers.

The ASAR attitude display was not very beneficial during daytime AAMD maneuvers, unless the pilot's eyes were looking behind the aircraft's wingline. Looking behind the aircraft when pulling g's and trying to adjust bank for level flight was easier with the ASAR (i.e. with BL+ or ANDFR) than with just the BL symbology. The digital flight path angle and analog bank were the first indications to the pilot that the aircraft was climbing or descending. This could be critical information for preventing unintentional descents and potential ground impact during low altitude defensive reactions. Having the ASAR automatically added to the BL set when at low altitude (<5000 ft AGL) could cue the pilot to avoid ground impact especially when looking behind the aircraft wingline.

Air-to-Ground:

When cross-checking HUD information during off-boresight target search tasks, pilots naturally scanned their eyes to the HUD versus rotating their whole head (and helmet) to the HUD boresight. Implementation of a virtual HUD in the HMD will need to allow pilots to use their peripheral vision as well as a glancing look at the azimuth limits of their eye scan. Otherwise, pilots will need to rotate their head more towards aircraft boresight than normal HUD operations which would increase pilot workload, increase the time required to cross check HUD information, and potentially decrease task performance.

FUTURE TESTING

Testing was limited to day VMC conditions. Development of the off-boresight symbology should continue and include the recommended enhancements. Future testing should focus on low altitude all aspect missile defense maneuvers, medium/low altitude night employment tasks and formation flights on the wing in weather. If possible, any future testing should include sensor and weapons information displayed in the HMD. **The recommended enhancements should be tested with multiple sensor and weapons information included in the display as well as during other than day VMC condition (R8).**

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CONCLUSIONS AND RECOMMENDATIONS

This evaluation was conducted during day visual meteorological conditions (VMC) only. However, conclusions were made considering the potential employment during night or instrument meteorological conditions (IMC), as well as with weapon and multi-sensor information included in the helmet-mounted display (HMD).

Pilots using the Advanced Non-Distributed Flight Reference (ANDFR) symbology in the HMD were able to accurately recall more data than when using either the Baseline Plus (BL+) or MIL-STD-1787C Head Up Display (HUD) symbologies. Pilots using BL+ symbology were able to recall more data than with the HUD symbology. Pilots generally preferred the ANDFR to BL+ or the HUD for static parameter recall because everything was found in one place. However, the BL+ and ANDFR bank information was identified as being somewhat difficult to interpret at nose high attitudes. A better horizon reference would improve the quick recognition of bank angle at any flight path angle (FPA).

During unusual attitude (UA) recovery flight tests, ANDFR did not provide quicker reaction times or more correct inputs than BL+. Pilots showed a preference for BL+ over ANDFR and BL symbologies during UA recoveries. This was due to less mental workload when transitioning from off-boresight to the HUD for completion of the recovery. The Arc Segmented Attitude Reference (ASAR) in the BL+ and ANDFR symbologies was found to aid in UA recognition and recovery. However, quickly interpreting nose high attitudes using the ASAR was consistently more difficult than nose low attitudes and caused a few incorrect initial recovery inputs. This was primarily due to an insufficient off-boresight horizon display.

During the medium altitude air-to-air task, pilots concluded that the BL set would be most beneficial when considering the addition of weapons and on/off-board sensor information in the HMD. The BL symbology set was the least distracting, allowed for a better cross check between aircraft flight parameters and target location, and was easy to use when quickly transitioning between on and off-boresight. Task performance using the BL was approximately the same as when using BL+ or ANDFR. However, pilot workload was reduced and situation awareness was higher when using BL. This allowed pilots to spend more of the off-boresight time searching for the target than interpreting the symbology. Pilots felt the addition of an off-boresight radar altimeter display would aid in task performance and ground avoidance during low altitude tasks.

For the medium altitude air-to-ground close air support (CAS) and the low altitude pop attack tasks, BL was preferred during daytime employment. Using BL resulted in approximately the same performance as the other symbologies, but was the least distracting, easiest to interpret, and allowed for more target search time. However, day employment with a discernable horizon did not require an off-boresight attitude reference. The BL+ could be beneficial during target searches at night or with no horizon while still not causing objectionable distraction or difficulties when transitioning to and from the HUD. However, the BL+ aircraft heading was not needed off-boresight, and the ASAR was too high for easy cross check during either air-to-ground task. Pilots did not like the ANDFR altitude and airspeed odometers for use as trend information. The odometers were very difficult to quickly adapt too when attempting to gain trend or precision information. The similar format and position of altitude and airspeed in the BL (or BL+) set to that of the HUD reduced mental workload, reduced display fixation and ultimately increased available target search time.

The following recommendations were made to enhance the off-boresight HMD symbology for improved operational task performance, situational awareness and safety.

The BL symbology was most preferred for operational tasks due to the limited clutter and distraction. **The Baseline symbology should be used as the default off-boresight symbology set. (R5, page 30)**

The BL symbology did not provide a sufficient attitude reference for recognition of unusual attitudes when looking off-boresight. Allowing the pilot to add the Arc Segmented Attitude Reference (ASAR) to the BL set for different mission environments would aid in unusual attitude recognition.
System integration of off-boresight HMD symbology should incorporate a pilot programmable declutter option. (R7, page 32)

The off-boresight horizon reference did not allow for quick recognition of bank at nose high altitudes. **The off-boresight horizon reference should be improved. (R1, page 10)**

The ASAR analog FPA display had insufficient resolution for quick interpretation of small flight path angles. Interpreting the digital FPA display required too much time and effort.
The off-boresight analog flight path angle reference should be improved for quicker interpretation of flight path angles less than 20°. (R3, page 20)

Radar altitude was required by the pliots when flying in close proximity to the ground.
A radar altitude display should be added to the off-boresight display. (R2, page 20)

The aircraft heading tape in the BL+ symbology set was too distracting and rarely used. Helmet heading was deemed to be more tactically beneficial than aircraft heading.
The off-boresight heading display should be modified to represent helmet heading and be less distracting. (R4, page 20)

The ASAR was located too high (65 mils above HMD center field of view) for easy crosscheck during air-to-ground tasks.
The off-boresight attitude reference display should be positioned low in the HMD field of view for easy parameter cross check during air-to-ground tasks. (R6, page 31)

The test symbologies would eventually incorporate multiple sensor/weapon cues during formation, night and IMC conditions (realistic combat conditions). Testing was not accomplished in these areas.
The recommended enhancements should be tested with multiple sensor and weapons information included in the display as well as during other than day VMC conditions. (R8, page 33)

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APPENDIX A: Pilot Rating Scales

SA SCALE VALUE	CONTENT
VERY GOOD – 1	• FULL KNOWLEDGE OF A/C ENERGY STATE / TACTICAL ENVIRONMENT / MISSION • FULL ABILITY TO ANTICIPATE / ACCOMODATE TRENDS
GOOD – 2	• FULL KNOWLEDGE OF A/C ENERGY STATE / TACTICAL ENVIRONMENT / MISSION • PARTIAL ABILITY TO ANTICIPATE / ACCOMMODATE TRENDS
ADEQUATE – 3	• FULL KNOWLEDGE OF A/C ENERGY STATE / TACTICAL ENVIRONMENT / MISSION • SATURATED ABILITY TO ANTICIPATE / ACCOMMODATE TRENDS • SOME SHEDDING OF MINOR TASKS
POOR – 4	• FAIR KNOWLEDGE OF A/C ENERGY STATE / TACTICAL ENVIRONMENT / MISSION • SATURATED ABILITY TO ANTICIPATE / ACCOMMODATE TRENDS • SHEDDING OF ALL MINOR TASKS AS WELL AS MANY NOT ESSENTIAL TO FLIGHT SAFETY / MISSION EFFECTIVENESS
VERY POOR – 5	• MINIMAL KNOWLEDGE OF A/C ENERGY STATE / TACTICAL ENVIRONMENT / MISSION • OVERSATURATED ABILITY TO ANTICIPATE / ACCOMMODATE TRENDS • SHEDDING OF ALL TASKS NOT ABSOLUTELY ESSENTIAL TO FLIGHT SAFETY / MISSION EFFECTIVENESS

Figure A1: China Lake Situation Awareness (CLSA) Scale

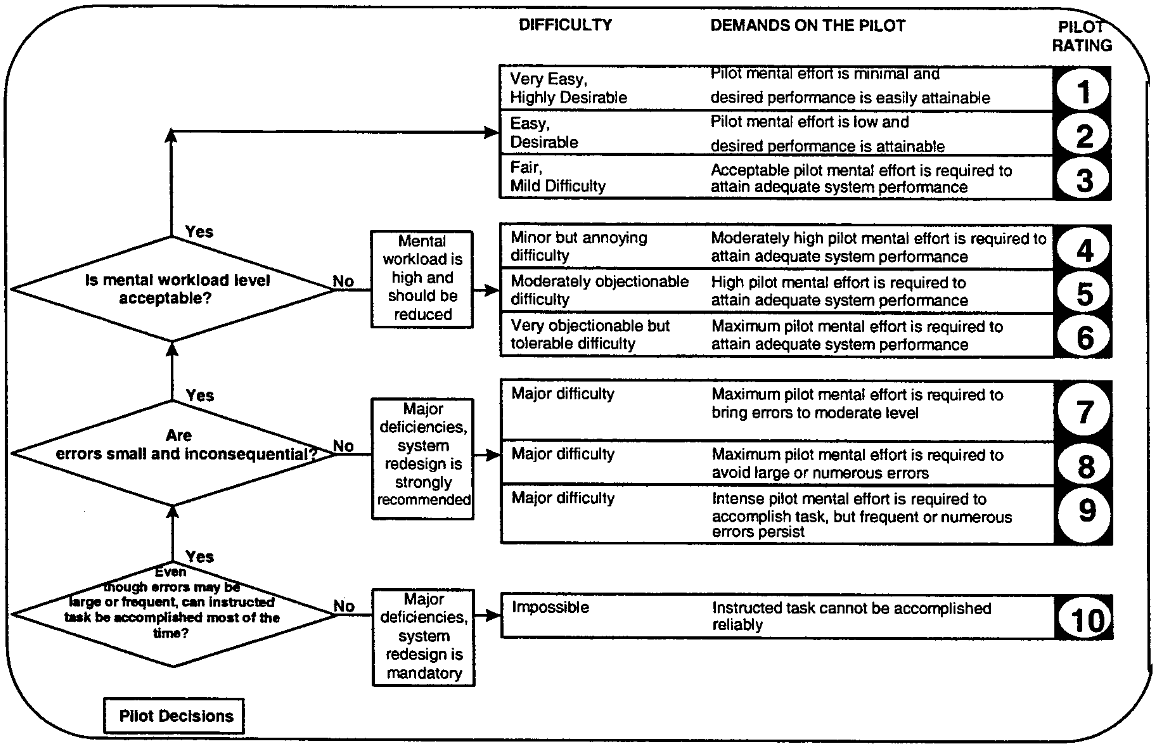

Figure A2: Modified Cooper-Harper (MCH) Rating Scale

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APPENDIX B: Test Resources and VISTA Simulation System (VSS)

TEST RESOURCES

Simulator:

The VISTA ground simulation mode was used to familiarize aircrew (pilots, engineers, and weapons system officer) with the HMD and the various display symbologies. Aircrew used VISTA in this ground simulator mode to become familiar with the maneuvers, recovery procedures, and the use of the rating scales to be used in flight test. The VSS simulation mode was used for a build-up approach prior to flight and also to gather ground test data.

Each aircrew was scheduled for a VISTA HMD familiarization and ground test session. These sessions were administered with the assistance of a Veridian test engineer. Each aircrew performed recall of own-ship parameters, practiced recovery from unusual attitudes, flew simulated air-to-ground and air-to-air operational scenarios, and practiced giving ratings and comments.

Test Aircraft:

Variable-stability In-flight Simulator Test Aircraft (VISTA) NF-16D.

The NF-16D Variable-stability In-flight Simulator Test Aircraft (VISTA, USAF S/N 86-0048) was a modified F-16D Block 30, Peace Marble II (Israeli version) aircraft with a Digital Flight Control System (DFLCS) using Block 40 avionics and powered by an F110-GE-100 engine. All necessary controls were moved from the front to the aft cockpit to allow the pilot in command or safety pilot (SP) to fly from the aft cockpit. The aft cockpit had conventional F-16 controls except the servo-driven throttle, which followed electrical commands of the front cockpit when the VISTA Simulation System (VSS) was engaged. Primary VSS controls, displays, and system engagement were located in the aft cockpit. Front cockpit included the VSS control panel needed to engage the variable feel center stick or sidestick, but the VSS system could only be engaged from the aft cockpit. Front cockpit Multi-Function Displays (MFDs) also reflected the aft cockpit MFDs and could be used for simulation configuration controls if necessary. Other modifications to the aircraft included a higher flow rate hydraulic system with increased capacity pumps and higher rate actuators as well as modifications to electrical and avionics systems required to support VSS operations.

The EP flew the test points from the front cockpit utilizing the side stick controller. Test points were flown in either the VSS (unusual attitudes) or F-16 VISTA (all operational tasks) operating modes. The rear cockpit SP set up the VSS computer and the HMD configurations, performed routine F-16 flight procedures, and monitored the safety of the evaluations. At any time, the SP could disengage the VSS and take control of the aircraft.

Veridian Flight Research developed VISTA software to implement the test maneuvers described in this test plan. The VISTA instrumentation system was set up to aid in timing, measuring, calculating, displaying, and recording test events as well as maneuver performance.

The layout of major components in the VISTA F-16 is shown on Figure B1.

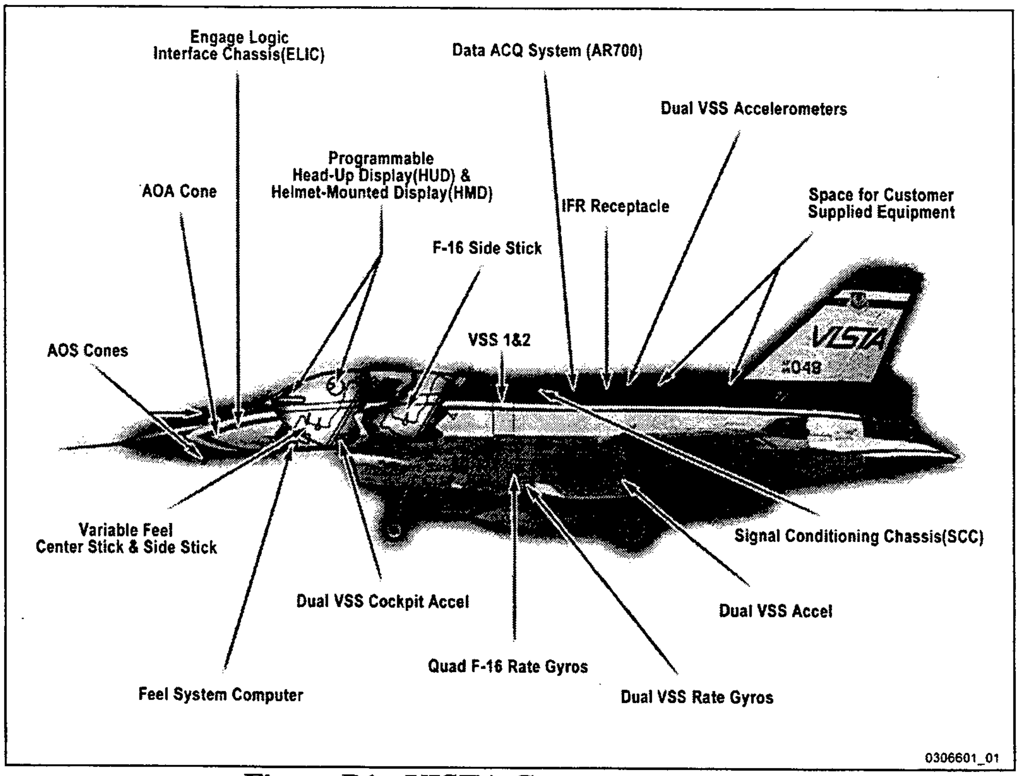

Figure B1: VISTA Component Layout

VISTA's Display System:

Programmable Display System (PDS):

The PDS equipment installed in the aircraft included these major components:

- VISTA Viper-IV Helmet Mounted Display
- Viper-IV Helmet with associated electronics unit and other cockpit units and cable assemblies
- Helmet Tracker Transmitter (HTT) and associated electronics units
- HUD Electronics Unit Switching Unit (HEUSU)
- HMD Camera Electronics Unit

A sketch of the PDS equipment is given in Figure B2. This sketch provides a general layout of the PDS equipment and its interconnection. The Viper-IV HMD and associated tracking system were installed in the front cockpit of VISTA. The programmable displays (both HUD and HMD) were the primary displays for the EP, who occupied the front cockpit.

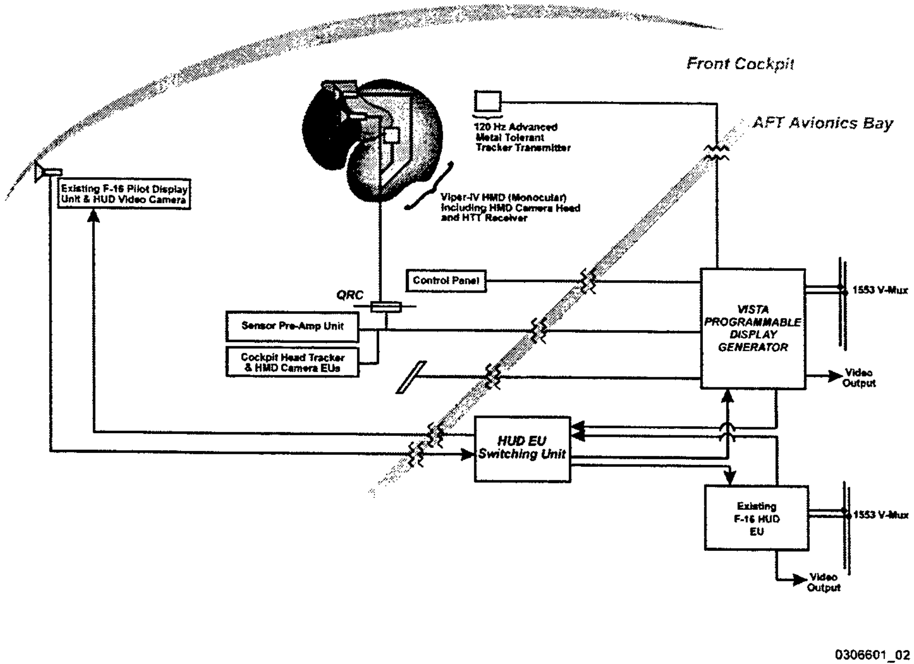

Figure B2: Programmable Display System (PDS) General Schematic Diagram

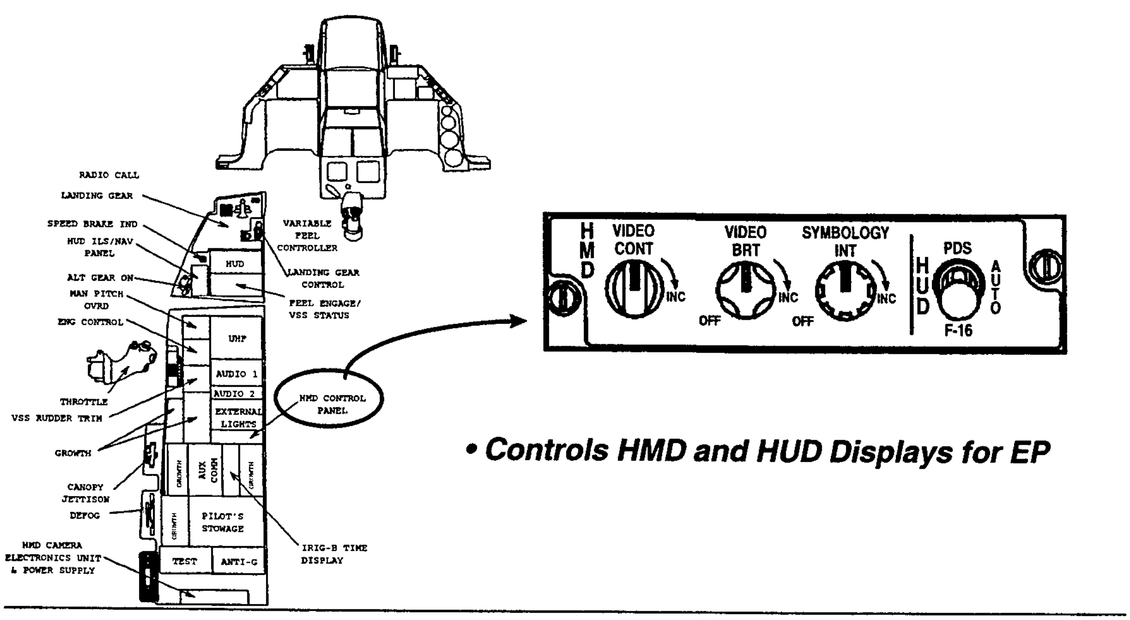

Figure B3: HMD Control Panel

The front seat HUD Pilot Display Unit (PDU) displayed either the nominal F-16 HUD or the programmed HUD display from the PDS (i.e., the PDS HUD). The display selection was activated by the HEUSU (Figure B2). The HEUSU was controlled by a switch located on the HMD control panel in the front cockpit (Figure B3). From this switch, the programmable HUD (forward switch position – "PDS") could be selected manually or the selection could be made by VSS computer control (center position – "AUTO").

The rear cockpit, occupied by the SP, was essentially unaffected by the PDS with the notable exception that the PDS power switch was on the avionics power panel in the rear cockpit (on the non-essential avionics bus) and video switches had been added so the SP could, at any time, view the same displays as the EP (HUD or HMD) on either the right Multi-Function Display (MFD) or Aft Seat HUD Monitor (ASHM). The EP could also view the nominal F-16 HUD on either the ASHM or right MFD at any time, in addition to the PDS HUD or HMD.

Helmet Mounted Display (HMD)

Viper-IV HMD

The Viper-IV HMD and associated head tracking system were installed in the front cockpit of VISTA. The programmable displays (both HUD and HMD) were the primary displays for the EP. The most prominent item of the PDS was the Viper IV HMD. The BAE Systems Viper IV HMD, shown in Figure B4, was a monocular, 40 degree field-of-view stroke HMD, installed on a slightly modified HGU-86/P helmet shell. An MBU-20/P oxygen mask was used.

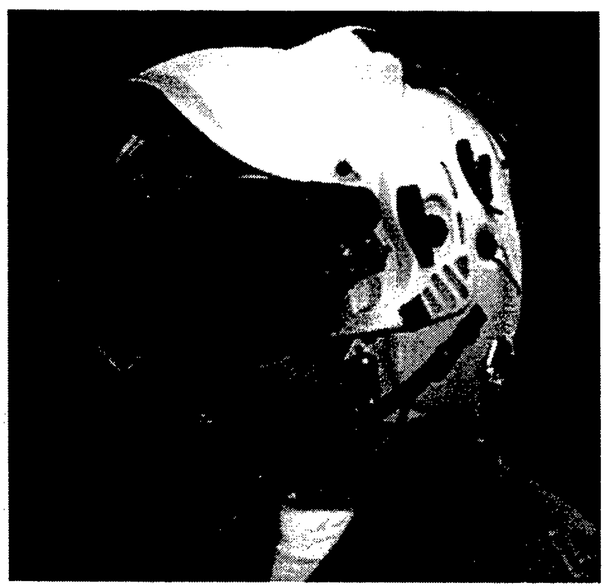

Figure B4: VISTA Viper-IV HMD

Head position and angular orientation data were obtained via the Honeywell Advanced Metal Tolerant Head Tracking system installed in the front cockpit. These data were used to generate the aircraft-stabilized virtual HUD symbology and the off-boresight HMD symbologies. Due to a malfunctioning helmet tracker, the virtual HUD could not be used in this evaluation.

VISTA Simulation System (VSS)

The VSS consisted of three flight qualified digital computers which interfaced with F-16 DFLCS, associated sensors, signal conditioners, and displays. For in-flight simulation VISTA used an implicit model following technique where the aerodynamic model and VSS feedback gains were used to model unaugmented response characteristics. VSS computers also hosted flight control laws, which allowed VISTA to generate closed loop response characteristics. VISTA's fully programmable variable feel system could model non-linearities such as breakout, friction, soft-stops, hard-stops, and multiple stick gradients as well as adjust stick frequency and damping. VISTA had the capability to change stick characteristics and certain flight control gains during the course of a flight using either MFDs or stored programs. However, only those gains and characteristics which were previously ground simulated on VISTA and verified to properly operate would be tested in flight. VSS also included built-in test functions, software safety trips, safety trip reporting, engage and disengage logic, and VISTA Vehicle Integrity Monitor (VIM) logic. The F-16 control laws were used in VISTA for all ground and flight tests. VISTA flight control modes were as follows:

1) DISENGAGED MODE: The Safety Pilot (SP) in the aft cockpit was in control of the aircraft and his inputs were processed through the standard F-16 digital flight control laws. The VSS was out of the loop. This mode was the default on power up and could be entered directly from any other mode.

2) F-16 MODE: The Evaluation Pilot (EP) in the front cockpit was in control of the aircraft and his inputs were processed through the standard F-16 digital flight control laws. The F-16 Mode was entered from the Disengaged Mode and returned to the Disengaged Mode when any of the safety trips were activated.

3) F-16 EMERGENCY MODE: The EP in front cockpit was in control of the aircraft and his inputs were processed through the standard F-16 digital flight control laws. The Emergency Mode could be entered from any mode but was intended for use only if the SP was incapacitated or the aft cockpit controls were malfunctioning. If the EP deselected the Emergency Mode, the aircraft reverted to the F-16 Mode. If the SP deselected the Emergency Mode, the aircraft reverted to the Disengaged Mode.

4) VSS MODE: The EP in the front cockpit was in control of the aircraft and his inputs were processed through VSS using the simulated control laws and aerodynamics. The VSS Mode was entered from the Disengaged Mode and returned to Disengaged Mode when any of the safety trips were activated.

APPENDIX C: Ground Simulation Information Recall Test Data

Table C1: BL Information Category Recall Data

Aircrew	Information Recall Scores				
	Heading	Airspeed	Altitude	Bank Angle	Flight Path Angle
Pilot 1	0	0	0	2	1
	0	0	0	1	0
	0	0	0	2	1
	0	0	0	2	1
	0	0	0	2	0
	0	0	0	1	0
Pilot 2	0	2	2	0	2
	0	0	2	0	0
	2	0	0	0	2
	0	0	1	0	1
	0	0	1	1	2
	0	0	0	2	2
Pilot 3	0	0	0	0	0
	0	0	2	0	0
	0	2	0	0	0
	0	2	0	0	0
	0	0	0	0	0
	0	0	1	0	0

Table C2: BL+ Information Category Recall Data

Aircrew	Information Recall Scores				
	Heading	Airspeed	Altitude	Bank Angle	Flight Path Angle
Pilot 1	0	0	0	2	2
	0	0	0	2	2
	0	0	0	2	2
	0	0	0	2	2
	0	0	0	2	2
	0	0	1	2	2
Pilot 2	0	1	0	0	0
	0	2	0	1	0
	0	2	0	0	1
	0	0	2	1	2
	0	0	2	0	2
	0	2	0	1	2
Pilot 3	0	0	0	0	0
	0	2	0	0	0
	0	0	2	0	2
	0	2	0	0	0
	0	0	2	0	0
	0	0	0	0	2

Table C3: ANDFR Information Category Recall Data

	Information Recall Scores				
Aircrew	Heading	Airspeed	Altitude	Bank Angle	Flight Path Angle
Pilot 1	0	0	0	2	2
	0	2	0	2	2
	0	0	0	2	2
	0	0	0	0	2
	0	2	0	0	2
	0	2	0	2	2
Pilot 2	0	2	0	2	0
	0	2	2	2	2
	0	2	1	0	2
	0	1	0	2	2
	0	0	0	0	2
	0	1	1	2	2
Pilot 3	0	1	2	0	0
	0	2	2	0	0
	0	1	0	0	2
	0	0	0	0	2
	0	2	0	0	2
	0	0	2	0	0

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APPENDIX D: Statistical Computations

Statistical Analysis for Unusual Attitude Recovery Response Time

A one-tailed Student's T test was performed with an alpha of 0.05.

Null Hypothesis: The time to the first significant input for correct unusual attitude recoveries with ANDFR was greater than or equal to those performed with BL or BL+.

Alternate Hypothesis: The time to the first significant input for correct unusual attitude recoveries with ANDFR was less than those performed with BL or BL+.

The required T score to reject the null hypothesis was -1.86 or lower.

Table D1: Statistics for Flight Unusual Attitude Recovery Response Time

	BL	BL+	ANDFR
Pilot 1	2.5	1.56	1.74
	2.68	1.94	1.64
	1.88	1.7	1.98
	1.94	1.44	2.56
Pilot 2	1.62	1.24	1.2
	1.36	1.18	1.22
	1.44	1.6	1.38
	1.42		
Pilot 3	1.08	1.24	0.68
	1.12	1.42	0.36
	0.66	1.06	
Average	1.61	1.44	1.42
Standard Deviation	0.61	0.27	0.66
T Scores			
ANDFR vs BL -0.86		ANDFR vs BL+ -0.09	

In the case of both BL and BL+, we fail to reject the null hypothesis. The test team cannot conclude with 95% confidence that in-flight unusual attitude response times for ANDFR were lower than those of BL or BL+.

Statistical Analysis for Unusual Attitude Recovery Correctness

A one-tailed Student's T test was performed with an alpha of 0.05.

Null Hypothesis: Unusual attitude recoveries performed with ANDFR were correct less often or an equal number of times than those using BL or BL+.

Alternate Hypothesis: Unusual attitude recoveries performed with ANDFR were correct more often than those done using BL or BL+.

The required T score to reject the null hypothesis was 1.81 or greater.

Table D2: Statistics for Flight Unusual Attitude Recovery Correctness

Correctness of Recoveries			
	BL	BL+	ANDFR
Correct	11	10	9
Incorrect	1	2	2
Average	0.92	0.83	0.82
Standard Deviation	0.29	0.39	0.40
T Scores			
ANDFR vs BL -0.77		ANDFR vs BL+ -0.12	
Note: When computing averages and standard deviations a zero was used for a correct recovery and one for an incorrect recovery.			

In the case of both BL and BL+, we fail to reject the null hypothesis. The test team cannot conclude with 95% confidence that unusual attitude recoveries performed using ANDFR are correct more often than those performed using BL or BL+.

Statistical Analysis for Off-Boresight Time During the Air-to-Ground CAS Task

A one-tailed Student's T test was performed with an alpha of 0.05.

Tasks performed to the desired or adequate level were weighted to accept the entire off-boresight time. Unsatisfactory task performance resulted in a zero weight and no off-boresight time being accepted.

Null Hypothesis: The percentage of time spent looking off-boresight (weighted for performance) for tasks completed using ANDFR was less than or equal to the percentage of time for tasks performed using BL or BL+.

Alternate Hypothesis: The percentage of time spent looking off-boresight (weighted for performance) for tasks completed using ANDFR was greater than the percentage of time for tasks performed using BL or BL+.

The required T score to reject the null hypothesis was 2.02 or greater.

Table D3: Statistics for CAS Performance

BL Off-Boresight Time	Performance Achieved	BL+ Off-Boresight Time	Performance Achieved	ANDFR Off-Boresight Time	Performance Achieved
65	D	75	D	88	A
85	D	80	D	79	D
95	D	100	U	100	D
100	D	100	A	100	D
100	D	85	A	95	U
85	D	90	D	95	A
90	D				
Weighted Average		Weighted Average		Weighted Average	
88.6		71.7		77	
Standard Deviation		Standard Deviation		Standard Deviation	
12.15		36.15		38.56	
T Score: BL vs ANDFR		T Score: BL+ vs NDFR			
-0.67		0.31			
Note: Off-boresight times associated with Desired or Adequate performance were counted in their entirety. Off-boresight times associated with unsatisfactory performance were counted as zero.					

In the case of both BL and BL+, we fail to reject the null hypothesis. The test team cannot conclude with 95% confidence that the percentage of time spent looking off-boresight for tasks performed using ANDFR was higher than for those performed using BL or BL+.

Statistical Analysis for Off-Boresight Time During the Air-to-Ground Pop Attack Task

A one-tailed Student's T test was performed with an alpha of 0.05.

Tasks performed to the desired or adequate level were weighted to accept the entire off-boresight time. Unsatisfactory task performance resulted in a zero weight and no off-boresight time being accepted.

Null Hypothesis: The percentage of time spent looking off-boresight (weighted for performance) for tasks completed using ANDFR was less than or equal to the percentage of time for tasks performed using BL or BL+.

Alternate Hypothesis: The percentage of time spent looking off-boresight (weighted for performance) for tasks completed using ANDFR was greater than the percentage of time for tasks performed using BL or BL+.

The required T score to reject the null hypothesis was 2.02 or greater.

Table D4: Statistics for Pop Attack Performance

BL Off-Boresight Time	Performance Achieved	BL+ Off-Boresight Time	Performance Achieved	ANDFR Off-Boresight Time	Performance Achieved
80	D	75	D	75	D
90	D	75	D	85	A
70	D	85	D	85	D
50	U	90	D	70	A
70	A	60	U	95	U
60	U	60	U	70	U
		80	A		
Weighted Average		Weighted Average		Weighted Average	
51.67		57.86		52.50	
Standard Deviation		Standard Deviation		Standard Deviation	
40.70		39.88		41.08	
T Score: BL vs ANDFR		T Score: BL+ vs NDFR			
0.05		-0.29			
Note: Off-boresight times associated with Desired or Adequate performance were counted in their entirety. Off-boresight times associated with unsatisfactory performance were counted as zero.					

In the case of both BL and BL+, we fail to reject the null hypothesis. The test team cannot conclude with 95% confidence that the percentage of time spent looking off-boresight for tasks performed using ANDFR was higher than for those performed using BL or BL+.

Statistical Analysis for Off-Boresight Time During the All-Aspect Missile Defense Task

A one-tailed Student's T test was performed with an alpha of 0.05.

Tasks performed to the desired or adequate level were weighted to accept the entire off-boresight time. Unsatisfactory task performance resulted in a zero weight and no off-boresight time being accepted.

Null Hypothesis: The percentage of time spent looking off-boresight (weighted for performance) for tasks completed using ANDFR was less than or equal to the percentage of time for tasks performed using BL or BL+.

Alternate Hypothesis: The percentage of time spent looking off-boresight (weighted for performance) for tasks completed using ANDFR was greater than the percentage of time for tasks performed using BL or BL+.

The required T score to reject the null hypothesis was 2.02 or greater.

Table D5: Statistics for AAMD Performance

HUD Off-Boresight Time	Performance Achieved	VCATS Off-Boresight Time	Performance Achieved	NDFR Off-Boresight Time	Performance Achieved
90	D	95	D	95	A
90	A	95	A	95	D
100	D	100	D	100	D
100	D	99	D	100	D
65	A	70	A	90	A
80	A	85	A	99	A
Weighted Average		Weighted Average		Weighted Average	
87.5		90.7		96.5	
Standard Deviation		Standard Deviation		Standard Deviation	
13.32		11.43		3.94	
T Score: BL vs ANDFR		T Score: BL+ vs ANDFR			
5.11		3.31			
Note: Off-boresight times associated with Desired or Adequate performance where counted in their entirety. Off-boresight times associated with unsatisfactory performance were counted as zero.					

In the case of both BL and BL+, we reject the null hypothesis. The test team concludes with 95% confidence that the percentage of time spent looking off-boresight for tasks performed using ANDFR was higher than for those performed using BL or BL+.

APPENDIX E: Unusual Attitude Test Data

Table E1: Flight Test Unusual Attitude Recovery Data

	Time to First Significant Input								
Task Number	Pilot #1			Pilot #2			Pilot #3		
	BL	BL+	ANDFR	BL	BL+	ANDFR	BL	BL+	ANDFR
1	2.50	1.56	1.74	1.62	1.24	1.20	1.08	1.24	0.78
2	2.68	1.94	1.64	1.36	1.18	1.22	0.86	0.84	0.68
3	1.88	1.70	1.98	1.44	1.14	1.38	1.12	1.42	0.36
4	1.94	1.44	2.56	1.42	1.60	-	0.66	1.06	0.74
Mean Time to 1st Significant Correct Input (sec)	**2.25**	**1.66**	**1.98**	**1.46**	**1.34**	**1.27**	**0.95**	**1.24**	**0.52**
	Recovery Correctness								
Incorrect	0	0	0	0	1	0	1	1	2
Correct	4	4	4	4	3	3	3	3	2
Total	4	4	4	4	4	3	4	4	4
Percent Correct	**100%**	**100%**	**100%**	**100%**	**75%**	**100%**	**75%**	**75%**	**50%**

APPENDIX F: Operational Task Test Data

Table F1: AAMD Task Performance Data

	Symbology	CLSA Rating	MCH Rating	Altitude	Airspeed	Percent Off-Boresight Time
Pilot #1	BL	2	2	D	D	90
	BL	2	3	A	D	90
	BL+	1	2	D	D	95
	BL+	2	4	A	D	95
	ANDFR	2	3	A	D	95
	ANDFR	1	3	D	D	95
Pilot #2	BL	1	1	D	D	100
	BL	1	1	D	D	100
	BL+	2	2	D	D	100
	BL+	2	2	D	D	99
	ANDFR	2	2	D	D	100
	ANDFR	2	2	D	D	100
Pilot #3	BL	3	4	A	D	65
	BL	2	3	A	A	80
	BL+	3	5	A	D	70
	BL+	2	3	A	D	85
	ANDFR	2	3	A	A	90
	ANDFR	2	3	A	D	99

D – Desired Task Performance
A – Adequate Task Performance
U – Unsatisfactory Task Performance

Table F2: CAS Task Performance Data

	Symbology	CLSA Rating	MCH Rating	Altitude	Airspeed	Percent Off-Boresight Time
Pilot #1	BL	3	3	D	D	65
	BL	2	3	D	D	85
	BL	3	2	D	D	95
	BL+	2	3	D	D	85
	BL+	2	2	D	D	90
	ANDFR	2	3	A	D	88
	ANDFR	1	2	D	D	79
Pilot #2	BL	2	3	D	D	100
	BL	1	2	D	D	100
	BL+	3	5	U	A	100
	BL+	2	3	A	D	100
	ANDFR	2	3	D	D	100
	ANDFR	2	2	D	D	100
Pilot #3	BL	2	2	D	D	85
	BL	1	2	D	D	90
	BL+	2	3	A	D	85
	BL+	1	2	D	D	90
	ANDFR	2	4	U	A	95
	ANDFR	2	2	A	D	95

D – Desired Task Performance
A – Adequate Task Performance
U – Unsatisfactory Task Performance

Table F3: Pop Attack Task Performance Data

	Symbology	CLSA Rating	MCH Rating	Climb Angle	Roll-In Altitude	Percent Off-Boresight Time
Pilot #1	BL	1	2	D	D	80
	BL+	2	3	D	D	75
	BL+	1	3	D	D	75
	ANDFR	2	3	D	D	75
Pilot #2	BL	1	2	D	D	90
	BL	1	2	D	D	70
	BL+	2	2	D	D	85
	BL+	3	3	D	D	90
	ANDFR	3	4	A	D	85
	ANDFR	3	4	D	D	85
Pilot #3	BL	2	4	U	D	50
	BL	3	4	A	D	70
	BL	2	4	U	D	60
	BL+	3	5	U	D	60
	BL+	2	4	U	A	60
	BL+	2	2	A	D	80
	ANDFR	2	2	D	A	70
	ANDFR	2	3	U	U	95
	ANDFR	2	3	U	D	70

D – Desired Task Performance
A – Adequate Task Performance
U – Unsatisfactory Task Performance

APPENDIX G: Questionaires

Figure G1: Interpretability of Symbology Questionnaire

Pilot:__________________ Date:______________

Symbol set (circle one): BL / BL+ / ANDFR

1) How many fighter aircraft piloting hours do you have?____________________________
2) How many heavy aircraft piloting hours do you have?____________________________
3) How many hours in a HUD equipped aircraft do you have?________________________

1	2	3	4	5
Not Confident		Somewhat Confident		Very Confident

Using the scale above, circle your response to the following questions in relation to the symbol set you used during the flight test:
Consider determining the given parameter in the context of getting as much data as possible.

1) How confident are you that you could use it for determining heading?	1	2	3	4	5
2) How confident are you that you could use it for determining airspeed?	1	2	3	4	5
3) How confident are you that you could use it for determining altitude?	1	2	3	4	5
4) How confident are you that you could use it for determining bank?	1	2	3	4	5
5) How confident are you that you could use it for determining pitch?	1	2	3	4	5

Complete for BL+ and ANDFR (N/A for BL)

1	2	3	4	5
Symbol set Definitely Superior		Both About The Same		My instrumentation (HUD) Definitely Superior

Using the scale above, circle your response to the following questions comparing the symbol set you used during the flight test to the HUD:

1) Which allows better determination of heading?	1	2	3	4	5
2) Which allows better determination of airspeed?	1	2	3	4	5
3) Which allows better determination of altitude?	1	2	3	4	5
4) Which allows better determination of bank?	1	2	3	4	5
5) Which allows better determination of pitch?	1	2	3	4	5
6) Which allows better determination of unusual attitude recognition?	1	2	3	4	5
7) Which would you prefer in a combat display? (AA information)	1	2	3	4	5
8) Which would you prefer in a combat display? (AG information)	1	2	3	4	5

For 7 and 8 consider HUD+HMD or pure HUD.

Complete after seeing BL+ and ANDFR

1	2	3	4	5
BL+ Definitely Superior		Both About The Same		ANDFR Definitely Superior

Using the scale above, circle your response to the following questions comparing the HMD symbol sets:

1) Which allows better determination of heading?	1	2	3	4	5
2) Which allows better determination of airspeed?	1	2	3	4	5
3) Which allows better determination of altitude?	1	2	3	4	5
4) Which allows better determination of bank?	1	2	3	4	5
5) Which allows better determination of pitch?	1	2	3	4	5
6) Which allows better determination of unusual attitude recognition?	1	2	3	4	5
7) Which would you prefer in a combat display? (AA information)	1	2	3	4	5
8) Which would you prefer in a combat display? (AG information)	1	2	3	4	5

For 7 and 8 consider HUD+HMD or pure HUD.

Answer the following questions:

1) What element of the symbol set did you like the least?____________________________
2) What element of the symbol set did you like the most?____________________________
3) What improvements would you make to the symbol set?__________________________
4) Any additional comments:

Figure G2: Unusual Attitude Recovery Task Questionnaire

Pilot:____________________ Date:________________

Symbol set (circle one): BL / BL+ / ANDFR

1	2	3	4	5
Strongly Disagree		**Indifferent/Don't Know**		**Strongly Agree**

Using the scale above, **circle your response** to the following questions in relation to the symbol set you used during the flight test:

1) I was able to rapidly determine what unusual attitude that I was in from the projected symbology.	1	2	3	4	5
2) At first glance at the symbology, I was able to determine which control inputs were required for recovery.	1	2	3	4	5
3) As I performed the unusual attitude recovery, the symbology indications were confusing.	1	2	3	4	5
4) I was confident of my spatial orientation before the recovery.	1	2	3	4	5
5) I was confident of my spatial orientation during the recovery.	1	2	3	4	5
6) I was confident of my spatial orientation after the recovery.	1	2	3	4	5

1) What element of the symbol set did you like the least? Why?

2) What element of the symbol set did you like the most? Why?

3) What improvements would you make to the symbol set?

4) Any additional comments:

Figure G3: Air-to-Air Operational Task Questionnaire

Pilot:__________________ Date:______________

Symbol set (circle one): BL / BL+ / ANDFR

1 **Strongly Disagree**	2	3 **Indifferent/Don't Know**	4	5 **Strongly Agree**

Using the scale above, **circle your response** to the following questions in relation to the symbol set you used during the flight test:

1) The symbology was **un**obtrusive in the HMD FOV.	1	2	3	4	5
2) The symbology was easy to interpret.	1	2	3	4	5
3) I managed to adapt to the symbology early in the flight.	1	2	3	4	5
4) I had to look into the cockpit constantly to keep my SA.	1	2	3	4	5
5) I managed to use the symbology effectively off-boresight.	1	2	3	4	5
6) I feel comfortable using the symbology while off-boresight	1	2	3	4	5
7) I was disoriented at least once using it off-boresight.	1	2	3	4	5
8) The symbology was very helpful for the off-boresight task.	1	2	3	4	5
9) I had to really force myself to avoid looking inside.	1	2	3	4	5
10) I feel confident of using this symbology off-boresight.	1	2	3	4	5
11) I won't get into an UA while using this symbology.	1	2	3	4	5
12) If I get into a UA with this, I'm confident of recovering.	1	2	3	4	5
13) I liked this symbology set.	1	2	3	4	5

Answer the following questions:

1. What element of the symbol set did you like the least if any? Why?
2. What element of the symbol set did you like the most if any? Why?
3. What improvements would you make to the symbol set?
4. Any additional comments:

Figure G4: Air-to-Ground Operational Task Questionnaire

Pilot:__________________ Date:______________

Symbol set (circle one): BL / BL+ / ANDFR

1	2	3	4	5
Strongly Disagree		**Indifferent/Don't Know**		**Strongly Agree**

Using the scale above, **circle your response** to the following questions in relation to the symbol set you used during the flight test:

1) The symbology was **un**obtrusive in the HMD FOV.	1	2	3	4	5
2) The symbology was easy to interpret.	1	2	3	4	5
3) I managed to adapt to the symbology early in the flight.	1	2	3	4	5
4) I had to look into the cockpit constantly to keep my SA.	1	2	3	4	5
5) I managed to use the symbology effectively off-boresight.	1	2	3	4	5
6) I feel comfortable using the symbology while off-boresight	1	2	3	4	5
7) I was disoriented at least once using it off-boresight.	1	2	3	4	5
8) The symbology was very helpful for the off-boresight task.	1	2	3	4	5
9) I had to really force myself to avoid looking inside.	1	2	3	4	5
10) I feel confident of using this symbology off-boresight.	1	2	3	4	5
11) I won't get into an UA while using this symbology.	1	2	3	4	5
12) If I get into a UA with this, I'm confident of recovering.	1	2	3	4	5
13) I liked this symbology set.	1	2	3	4	5

Answer the following questions:

1. What element of the symbol set did you like the least if any? Why?
2. What element of the symbol set did you like the most if any? Why?
3. What improvements would you make to the symbol set?
4. Any additional comments:

Figure G5: Military Utility

Pilot/Aircrew:____________________ Date:______________

Symbol set (circle one): BL / BL+ / ANDFR

UNUSUAL ATTITUDES

1 Strongly Disagree	2	3 Indifferent/Don't Know	4	5 Strongly Agree

Using the scale above, **circle your response** to the following questions in relation to the symbol set you used during the flight test and provide tactical/operational comments :

1) Does the symbology provide sufficient cues to the pilot/aircrew to minimize reliance on cockpit instrument gauges during recovery?	1 2 3 4 5
2) Could the pilot/aircrew maintain situational awareness of threat or target information while recovering from unusual attitudes?	1 2 3 4 5

AIR-TO-AIR

1) What is the impact on achieving the desired mission effect during an all-aspect missile defense maneuver?

2) What additional considerations must be addressed for optimizing the symbology to successfully accomplish air-to-air tasks?

3) In what potential air-to-air environments would the addition of the symbology aid the pilot/aircrew in mission accomplishment?

4) In what potential air-to-air environments would the addition of the symbology cause distraction or have negative mission impact?

5) What will be the impact on how the Air Force trains air-to-air tactics if the addition of the symbology is pursued?

AIR-TO-GROUND

1) What is the impact of pilot/aircrew workload while attempting to achieve the desired mission effect during air-to-ground tasks (CAS or pop attack)?

2) Rate the projected performance of the symbology in a night, communication intensive, live fire, formation CAS combat scenario? (Circle one) Do you have any recommendations to improve mission capability with the symbology in this complex environment?

EXCELLENT GOOD NEUTRAL POOR UNSTAISFACTORY

3) How does the symbology enhance pilot/aircrew capability to achieve the desired mission effect during low altitude pop attack weapons release air-to-ground maneuvers?

4) What additional considerations must be addressed for optimizing the symbology to successfully accomplish air-to-ground tasks?

5) What will be the impact on how the Air Force trains air-to-ground tactics if the addition of the symbology is pursued?

APPENDIX H: Suggested Symbology Enhancements

Allow the pilot to program whether he wants the Arc Segmented Attitude Reference (ASAR) or the heading bar displayed in addition to the Baseline symbology set.

Add a horizon reference line, similar to the HUD, that rotates and moves up or down relative to the off-boresight flight path circle (Appendix H).

Add a horizon reference line, similar to the HUD, for comparison with the off boresight flight path circle (Appendix H).

When below 5000 ft AGL, add a digital radar altimeter preceeded by an "R" below the existing BL analog altitude dial.

Shorten the heading tape, but keep the 10° tick marks and the boxed digit heading.

Test during low altitude all aspect missile defense maneuvers, medium and low altitude night employment tasks, formation flight on the wing in instrument meteorological conditions (IMC) and with additional sensor/weapon information displayed in the HMD.

Pilot comments indicated that the ASAR had insufficient resolution for low climb and dive angles. Also, in very nose-high attitudes, the angle of bank of the aircraft was difficult to interpret.

One potential solution to these problems, the addition of a horizon line, was suggested by the test team and is shown in Figure H1. The suggested ASAR horizon line is similar to the horizon line in the HUD.

As shown in the Figure, the full travel of the line is +10° to –10° of pitch, but this is an arbitrary limit and should be adjusted as necessary based on further investigation. It is expected that a similar "mil per degree" relationship as the HUD uses would be most intuitive to pilots. Beyond these limits, the line changes from solid to broken, indicating that the range of travel has been exceeded, but still providing pilots with horizon location and orientation information.

The line rotates with the ASAR around the center aircraft/digital flight path display.

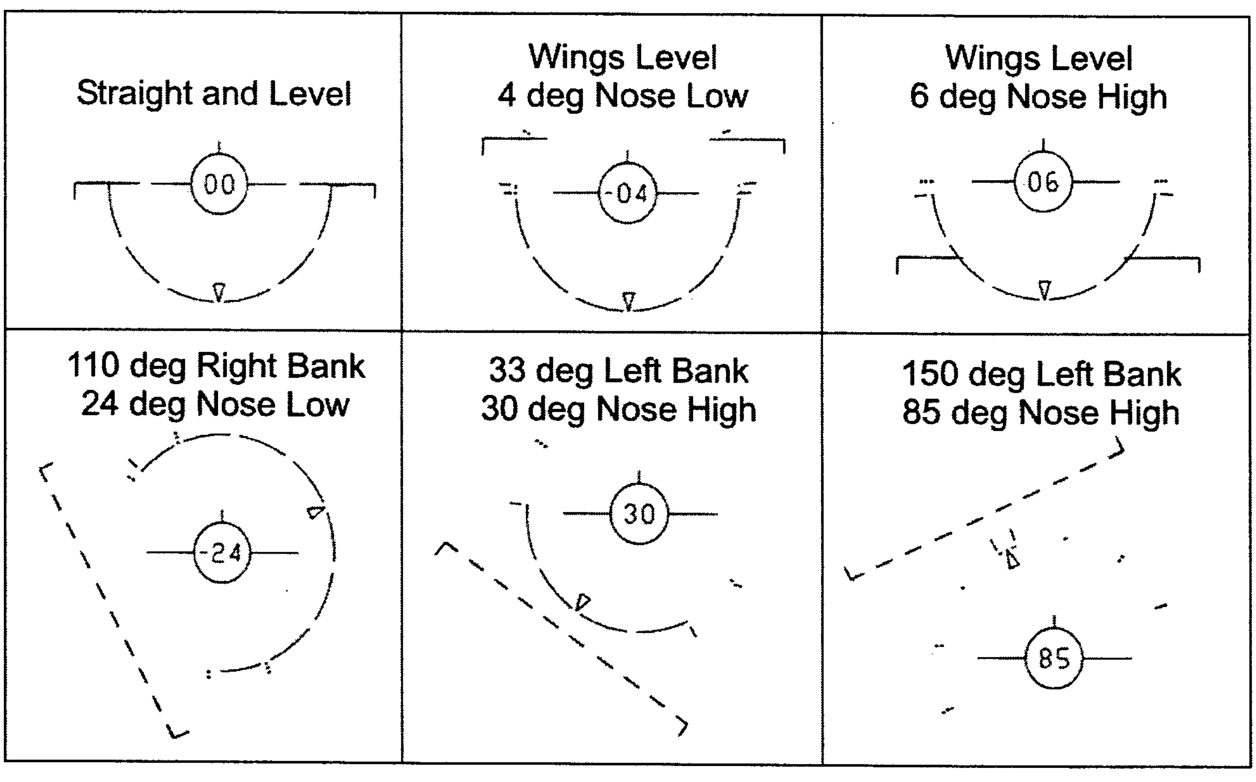

Figure H1: Suggested ASAR Horizon Enhancement Option

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APPENDIX I: List of Abbreviations, Acronyms, and Symbols

List of Abbreviations

Abbreviation	Definition	Units
A/A	Air-to-air	--
A/C	aircraft	--
AFFTC	Air Force Flight Test Center	--
AFRL	Air Force Research Laboratory	--
A/G	Air-to-ground	--
ANDFR	Advanced Non-Distributed Flight Reference	--
ASAR	Arc Segmented Attitude Reference	--
ASHM	Aft Seat HUD Monitor	--
BL	Baseline	--
BL+	Baseline Plus	--
CAS	Close Air Support	--
CLSA	China Lake Situational Awareness	--
Deg	degrees	--
DFLCS	Digital Flight Control System	--
EF	Evaluation Flight Test Engineer	--
EP	Evaluation Pilot	--
EN	Evaluation Flight Test Weapon Systems Officer	--
FAC(A)	Forward Air Control, Airborne	--
FDL	Fighter Data Link	--
FOV	Field of view	--
FPA	Flight Path Angle	deg
HEUSU	HUD Electronics Unit Switching Unit	--
HMD	Helmet Mounted Display	--
HTT	Helmet Tracker Transmitter	--
HUD	Head Up Display	--
JON	Job Order Number	--
JOAP	Joint Oil Analysis Program	--
kts	knots	kts
LOS	Line of Sight	--
MCH	Modified Cooper-Harper	--
MFD	Multi-Function Display	--
MOP	Measure of Performance	--
NDFR	Non-Distributed Flight Reference	--
N_z	Load Factor in Z axis	G
Obj	Objective	--
PA	Pressure altitude	ft
PDS	Programmable Display System	--
PDU	Pilot Display Unit	--
SA	Situation Awareness	--
Sec	seconds	sec
SP	Safety Pilot	--
SRB	Safety review Board	--
TA	Target Aircraft	--
TC	Test Conductor	--
TIM	Technical Information Memorandum	--
UA	Unusual Attitude	--
USAF TPS	United States Air Force Test Pilot School	--
VCATS	Visually Coupled Acquisition Targeting System	--
VIM	Vehicle Integrity Monitor	--
VISTA	Variable-stability In-flight Simulator Test Aircraft	--
VSS	VISTA Simulation System	--

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